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Evolution of the Surgeon Volume / Patient Outcome Relationship

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EVOLUTION OF THE SURGEON VOLUME / PATIENT OUTCOME RELATIONSHIP

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Introduction

Adams et al. was the first to demonstrate an association between improved outcomes and provider experience in a 1973 study examining complication rates from coronary arteriograms.[1] In this study, a questionnaire was mailed to the directors of coronary arteriography laboratories throughout the US. They found that mortality was eight times higher in institutions performing fewer than 200 examinations per two-year period compared to institutions performing more than 800 examinations per two-year period. It was not until 1979, however, that efforts to systematically study outcomes in surgery were made by Luft and colleagues.[2] They demonstrated lower mortality rates at high-volume centers compared with low-volume centers for several high risk procedures, such as coronary artery bypass graft surgery (CABG) and vascular surgery. This landmark study set the stage for outcomes research in surgery. Over the past decade, additional studies have continued to show higher surgeon or hospital volumes to be associated with improved patient outcomes. [3-13] To what degree surgeon versus hospital volume each contribute to outcomes is controversial and depends on the procedure examined. Nevertheless, formal recommendations encouraging certain high-risk procedures be performed at high-volume hospitals began as early as 2000 by the Leapfrog group and other policy initiatives.[14, 15] Formal recommendations for surgeon volume, on the other hand, have been lacking. There has been mounting evidence, particularly in the last decade, that surgeon volume is associated with improved patient outcomes, independent of hospital volume. To what measure these data have influenced referral patterns from low- to high-volume surgeons is unknown.

Hospital Volume

Health services research in surgery has led payers to practice so-called "evidence-based hospital referral" (EHR). The most visible of such efforts was initiated by the Leapfrog group in 2000. This organization, which was initiated as a result of a coalition of more than 150 public and private healthcare purchasers representing 40 million people, sought to improve patient outcomes by encouraging referrals to hospitals for certain procedures which met minimal-volume standards. Leapfrog establishes minimum caseloads for certain procedures if it deems there are sufficient data to support an association between higher hospital volume and improved outcomes (e.g. mortality). The original Leapfrog procedures were CABG, coronary angioplasty, elective repair of abdominal aortic aneurysm, and esophagectomy for cancer.[14] Leapfrog's EHR strategy established rigid thresholds defining high- and low-volume hospitals. These thresholds were established based on data from clinical research showing outcome differences as a function of hospital volume. According to Birkmeyer, a proponent of EHR, this initiative has the potential to save 7,602 lives year in the U.S. if implemented nationally.[14]

Surgeon Volume

The Leapfrog group has focused on hospital volume as a proxy for quality of care in surgical procedures. There is mounting evidence that individual surgeon experience also is associated with outcomes from several surgical procedures, independent of hospital volume. Chowdhury et al. systematically reviewed the literature examining the impact of surgeon volume on patient outcomes.[16] In this review, 58 studies focusing on surgeon-volume outcome relationships were analyzed. Outcomes varied by study design; each examined either mortality, hospital length of stay (LOS), and/or complications. Procedures included: colectomy, esophagectomy, pancreatic resection, gastrectomy, and lung lobectomy for cancer; two vascular procedures, CABG and carotid endarterectomy (CEA); and thyroidectomy for both benign and malignant disease. Forty three studies (74%) concluded that high surgeon volume was associated with significantly better overall outcomes.

For thyroidectomy, Chowdhury examined a population based study by Sosa et al. examining clinical and economic outcomes following thyroidectomy in relation to surgeon experience.[17] While several small institutional studies had shown that high-volume surgeons had low complication rates, they provided no benchmark for comparison to ordinary community surgeons and did not examine outcomes on a population scale. [17] This is important because the majority of thyroid surgeries are performed by general surgeons.[18] In this study, Sosa et al. used a cross-sectional analysis of hospital discharge data from the Maryland Health Services Cost Review Commission to identify patients who underwent a primary procedure of thyroidectomy for any reason between 1991 and 1996. Independent variables included thyroid diagnosis, age, gender, race, payer status, and the Dartmouth-Manitoba adaptation of the Charlson comorbidity score. Surgeon experience was modeled as a four way categorical variable (1-9, 10-29, 30-100, and >100 thyroid procedures per year). According to this study, there was a significant association between increased surgeon volume and improved outcomes. The highest volume surgeons in this study had the shortest LOS both before and after adjustment for differences in patient case-mix. Importantly, in a stratified multivariate analysis, they found that surgeon experience was a particularly important predictor of outcomes in patients with complex or severe disease (e.g. thyroid cancer patients who required a total thyroidectomy versus a partial thyroidectomy for a benign adenoma). The highest volume surgeon group had 75% fewer postsurgical complications ($p<0.001$) and the lowest charges ($p<0.001$) compared to low-volume surgeons. Sosa et al. estimated that more than 20% of complications and 1700 hospital days could have been saved in Maryland if all thyroidectomies were performed by high-volume surgeons. As a result, they concluded that patients undergoing thyroidectomy, and especially those with complex or severe thyroid disease, should be directed to a high-volume surgeon.

Other studies have examined the importance of surgeon experience as a predictor of outcomes for oncologic procedures. For example, Hannan et al. examined the influence of surgeon volume and post-operative mortality for colectomy, gastrectomy, and lung lobectomy in patients with cancer.[10] This study used the New York Statewide Planning and Research Cooperative System to identify more than 32,000 hospital inpatients with a cancer diagnosis that underwent one of the aforementioned procedures. This study simultaneously examined the impact of both surgeon and hospital volume. For colectomy, patients were identified using a principal procedure code for colectomy (e.g. right hemicolectomy, resection of the transerve colon, left hemicolectomy, or sigmoidectomy) and a related cancer diagnosis code (e.g. colon cancer). Similar strategies were used to identify patients undergoing lung lobectomy and gastrectomy. Comorbidities were identified using secondary diagnosis data. Adjustment was made using patient age, gender, race, and insurance status variables in their multivariate models. Overall, the authors found that high surgeon volume was independently associated with inpatient mortality for all three procedures in a step-wise, dose-dependent fashion as defined by surgeon-volume quartile. Surgeons in the 75th percentile or above, for example, had an adjusted mortality rate that was 5.74 ($p<.0001$) times lower than surgeons in the 25th percentile for gastrectomy, 1.86 ($p<.0001$) times lower for colectomy, and 1.12 ($p<.08$) times lower lung lobectomy.

Porter and colleagues examined the prognostic importance of surgeon experience for rectal cancer using a prospective study design with historic controls. They reviewed the records of patients with >5 year follow up from 52 surgeons at five hospitals over an eight year period in order to assess whether surgeon volume is associated with cancer patients' risk for local recurrence and survival. Six hundred eighty three patients were identified. All patients undergoing potentially curative low anterior resection (LAR) or abdominoperineal resection for adenocarcinoma of the rectum were included in the study. Demographic, preoperative, intraoperative, pathologic, adjuvant therapy, and outcome variables were obtained through a standardized review of hospital and physician charts. They found that disease specific survival rates were significantly lower for high-volume colorectal surgeons compared with low-volume surgeons. For example, patients who underwent surgery by a low-volume surgeon were 1.52 times (95% confidence interval 1.05-2.20) more likely to die of rectal cancer than patients treated by a high-volume colorectal specialist. The operative approach to these patients differed between surgeon groups. Surgeons performing <21 resections over the study period were significantly less likely to perform an LAR and preserve the anal sphincter.

Statement of Purpose

Evidence that improved outcomes are associated with high surgeon-volume independent of hospital volume for several specialized surgical procedures has mounted in the last decade.[16] The degree to which this evidence has influenced the number of patients who see a high- compared to low-volume surgeon is unknown. Further, it is unknown on a population level how such referral pattern shifts over time are associated with patient outcomes (e.g. mortality or LOS). Thus, we sought to answer the following two questions: 1) Are more patients being referred to high-volume surgeons and away from low-volume surgeons over time? 2) Are patient outcomes still better now when high-volume surgeons perform the procedure compared to low-volume surgeons?

Aims of Study

1) To determine if high-volume surgeon share has increased between 1999 and 2005 for surgical procedures for which abundant data exist supporting a positive surgeon-volume / patient-outcome relationship.
2) To measure whether patient outcomes (e.g. LOS and mortality[1]) are still different in 2005 compared to 1999 when high-volume surgeons perform a procedure compared to low-volume surgeons.

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[1] For thyroidectomy, outcomes of interest are LOS and endocrine-specific complications, since post-operative mortality is extremely rare.

Hypothesis

The hypothesis in this study was that there will be an increase in the proportion of patients who sought care from a high-volume surgeon in 2005 compared to 1999. This is likely associated with improved patient outcomes, and high-volume surgeons will continue to have superior outcomes compared to low-volume surgeons over time.

Methods

Data Source

This study is a cross-sectional analysis comparing 1999 and 2005 patient discharge information obtained from the Health Care Utilization Project National Inpatient Sample (HCUP-NIS) administrative database. The Agency for Healthcare Research and Quality (AHRQ), one of 12 agencies within the Department of Health and Human Services, maintains HCUP-NIS.[19] HCUP-NIS is the largest all-payer inpatient database in the U.S., with data from approximately 8 million hospital stays each year. There are more than 900 hospitals in this dataset, randomly selected within strata for region, number of hospital beds, teaching status, urban vs. rural location, and hospital ownership. HCUP-NIS contains data from 24 states in 1999, and 37 states in 2005 (Table 1).

Table 1: Summary of HCUP-NIS Data Sources

Year	Number of hospitals	Number of discharges in the NIS unweighted	Number of discharges in the NIS weighted for national estimates	States in sample
1999	984	7198929	35467673	AZ CA CO CT FL GA HI IL IA KS MD MA ME MO NJ NY OR PA SC TN UT VA WA WI
2005	1054	7995048	39163834	(Added states) KY NC TX WV MI MN NE NH RI VT NV OH SD IN (VA removed)

These datasets represent a 20% sample of all inpatient admissions to acute care hospitals nationwide.[19] The NIS is a publicly available dataset and contains no personal identifying information. This study was therefore deemed exempt from Human Investigation Committee approval at our institution (HIC # 0801003415).

We obtained data from 1999 and 2005 in order to assess whether high-volume surgeon share increased over time for procedures shown in the literature to have strong surgeon-volume associations. In order to do this, we relied upon a recently published systematic review by Chowdhury from the British Journal of Surgery, which examined evidence regarding the impact of surgeon volume on patient outcomes.[16] In this review, a standardized methodology was used to assess study quality. We abstracted procedures which had particularly strong evidence for a surgeon volume outcome relationship. These studies were closely examined to assure that the outcome of interest was a primary endpoint used in our study (e.g. inpatient mortality as opposed to 5-year survival).

Procedures deemed appropriate for inclusion in this study are: colectomy, esophagectomy, pancreatic resection, gastrectomy, and lung lobectomy for cancer; two vascular procedures, CABG and CEA; and thyroidectomy for both benign and malignant disease. Primary outcomes of interest were LOS or mortality (or endocrine complications for thyroidectomy).

We used primary procedure and diagnosis codes from the International Classification of Diseases, Ninth Revision (ICD-9) or clinical classification system (CCS) to identify adult patients (≥18 years) who underwent one of these procedures (Appendix 1). For the oncologic procedures, patients were included if they had an associated primary diagnosis of cancer. For colectomy, four patients were excluded who had a primary procedure code for Soave or Duhamel rectal resection (which are pediatric procedures) as they likely represent a coding error. For CABG and CEA, we excluded patients who had a secondary procedure indicating other cardiac and peripheral vascular procedures that might have increased the likelihood of a negative outcome not due to CABG or CEA. For CABG, this included secondary procedures such as cardiac valve repair or CEA; for CEA, this included secondary procedures on valves or vessels of the heart.

Patients were also excluded if they did not have an associated surgeon identifier. Excluded patients represented between 40-55% of our sample, depending on the procedure. We therefore compared hospital and patient characteristics between patients who had a surgeon identifier and those who did not in order to make sure that our cohort was an appropriate representative sample.

Provider & Patient Characteristics

Surgeon Characteristics

In order to assess how high-volume surgeon share changed between 1999 and 2005, we had to establish annual volume threshold definitions of a high- versus low volume-surgeon. The definitions of high- and low-volume surgeon varies between different operations, and in some instances even between studies examining the same operation.[16] We relied upon Chowdhury's systematic review which defined surgeon volume thresholds according to the most rigorously performed studies for each procedure. Surgeon volume was modeled as a three-way categorical variable for high-volume, medium volume, and low-volume surgeons. (Table 2)

Table 2: Annual Surgeon Volume Thresholds

Procedures	Low-volume	Medium Volume	High-volume
Oncologic			
Colectomy	11	12-20	21
Esophagectomy	4	5-11	12
Pancreas Resection	1	2-4	5
Gastrectomy	2	2-4	5
Lung Lobectomy	22	23-49	50
Other			
Thyroidectomy	9	10-29	30
CEA	5	6-49	50
CABG	50	51-149	150

Surgeons were identified in HCUP-NIS as the admitting physicians for patients undergoing a procedure of interest. Previous studies using administrative databases have shown this method to be reliable.[20]

Hospital Characteristics

Independent hospital variables used in this study included hospital location (urban vs. rural); geographic region (northeast, midwest, south, west); and teaching status (teaching hospital vs. non-teaching). Since hospital volume is related to improved outcomes for many procedures, we created a dichotomous variable (low-volume or high-volume hospital) at the 75%th percentile in order to control for hospital volume phenemena. This value is comparable to Leapfrog Group hospital volume thresholds.[14]

Patient Characteristics

Independent patient demographic variables included gender, median household income ($1-35,999, $36,000-44,999, $45,000-58999, and ≥$59,000), race (white, black, Hispanic, other) and payer type (Medicare, Medicaid, private HMO, self-pay). Since HCUP-NIS does not provide data regarding elective versus emergent surgery in 1999, hospital admission type was used as a proxy. Non-routine hospital admission was defined as admission from the emergency room, another hospital or facility, or jail. Patient age was modeled as a three-way categorical variable (18-44, 45-64, ≥65 years) as has been done in similar studies examining discharge information for surgical procedures.[17, 21]

A modified comorbidity score was created for each procedure of interest using Deyo's method of adapting a Charlson comorbidity score from an administrative database.[22, 23] We modified the comorbidity definition for each procedure group to exclude conditions likely to reflect a patient's primary reason for admission or a complication of their procedure.[24, 25] Since this modified comorbidity score has not been validated for the procedures in our study, we benchmarked our scores with those published in previous studies. We found our scores comparable.[24, 25] This score was treated in all calculations as an ordinal variable; for clarity of presentation, we present it as a dichotomous variable (<3 not sick, ≥3 sick).

Patient Outcomes

Primary outcomes of interest were: inpatient mortality (for all procedures except thyroidectomy); endocrine-specific complications for thyroidectomy; and mean LOS.

We identified endocrine-specific complications for thyroidectomy using ICD-9 diagnostic codes in order to identify complications unique to thyroidectomy (Table 3). Since it is not possible to rate complication severity, this outcome was treated as a binomial variable (no complication vs. one or more). This method of analyzing complications in an administrative database has been used by Sosa and others.[17]

Table 3: Thyroidectomy Complications (ICD-9 Codes & Diagnosis)

Paralysis of vocal cords or larynx		
	478.30	laryngoplegia
	478.31	unilateral partial
	478.32	unilateral complete
	478.33	bilateral partial
	478.34	bilateral complete
Other		
	252.1	hypoparathyroidism
	275.41	hypocalcemia
	781.7	Tetany

Statistical Analysis

In order to determine how high-volume surgeon share has changed between 1999 and 2005, surgeon volume groups were compared by year using the chi square statistic for each procedure.

The distribution of patient characteristics among surgeon volume groups were compared using analysis of variance (ANOVA) for continuous variables (e.g. LOS) and the chi square statistic for categorical variables (e.g. race, hospital region, etc). Bivariate analyses were used to determine which variables were associated with our outcomes of interest (i.e. mortality or LOS). These analyses subsequently guided the selection of variables for adjustment in the multivariate regression models.

Multivariate logistic regression models were used to determine if mortality (or endocrine complications for thyroidectomy) was related to surgeon volume in 1999 and 2005. Adjustments were made for patient and provider characteristics including patient age, race, gender, income, admission type, comorbidity score, and insurance type; and hospital volume, region, teaching status, and location. In addition, adjustments were made for the use of laparoscopy for colectomy and thoracoscopy for lung lobectomy, since these technologic advances conceivably influenced outcomes. Multivariate linear regression models were used to determine if LOS was related to surgeon volume between years adjusting for the same patient and provider variables indicated above.

Data analysis and management were performed using SPSS Version 14.0 (Chicago, IL). All probability values are the results of two-sided tests, and values less than or equal to 0.05 are reported as significant.

Miscellaneous

Drs. Julie Ann Sosa and Sanziana Roman guided me through all steps of this project. The design idea for this study is credited to Dr. Sosa. All database work was performed by me, with occasional assistance from two fellow medical students, Kevin Cheung and Charles Tuggle. All statistical analyses were performed by me, with oversight from Dr. Sosa. In addition, I met with statistician Dr. James Dziura and Robert Wood Johnson Scholar Dr. Nancy Kim on one occasion for assurances and ideas regarding my methodology. The writing of this manuscript was accomplished entirely by me, with editing from Drs. Sosa and Roman. I also received minor editing suggestions from fellow medical student Sophia Liu.

Results

Provider Characteristics

There were a total of 16,230 unique surgeons identified in the 1999 and 2005 HCUP-NIS database who performed a procedure of interest. High-volume surgeons made up a minority of providers for all procedure groups in both years (Table 8).

Overall, there were significant differences in hospital characteristics between surgeon-volume groups for all procedures (Table 4). In 1999, high-volume surgeons operated more often than low-volume surgeons in the south for all procedures except esophagectomy and thyroidectomy. For these procedures, the high-volume surgeons operated most often in the northeast. This trend among high-volume surgeons operating most often in the south was maintained in 2005 for colectomy and lung lobectomy. Thus, relative to low-volume surgeons, high-volume surgeons shifted away from operating in the south for most procedures.

High-volume surgeons operated in urban hospitals (as opposed to rural) more often than low-volume surgeons for all procedures except CABG in 1999, and all procedures except lung lobectomy in 2005. Likewise, high-volume surgeons practiced more often at a teaching hospital for all procedures except CABG; however, for most procedures this proportion decreased over time. CABG was the exception; in 1999 more low-volume surgeons (75% compared to 55% for high-volume surgeons $p<0.001$) were at a teaching hospital, whereas in 2005 only 43% of low-volume surgeons were at a teaching hospital (compared with 86% for high-volume surgeons $p<0.001$).

Table 4: Hospital Characteristics According to Surgeon Volume by Year ±

Calander Year	1999				2005			
Surgeon Volume Cohorts	High	Med	Low	p value*	High	Med	Low	p value*
Oncologic Procedures								
Colectomy								
Geographic Region				0.001				0.001
Northeast	18.9	31.2	27.6		24.7	33.8	26.4	
South	63.1	57.2	54.1		47.8	41.8	44.3	
West	2.1	5.1	9.7		7.1	11.1	13.6	
Midwest	15.9	6.6	8.6		20.4	13.3	15.7	
Urban Hospital	98.6	83.5	82.9	0.001	93.6	90.1	82.8	0.001
Teaching Hospital	62.0	43.0	37.0	0.001	48.5	42.7	32.2	0.001
High Volume Hospital	58.6	27.9	21.2	0.001	46.2	31.3	19.9	0.001
Esophagectomy								
Geographic Region				0.001				0.001
Northeast	33.8	22.0	24.5		8.8	16.1	13.8	
South	29.7	14.6	57.8		28.8	16.1	40.9	
West	17.6	17.1	13.6		14.4	27.4	20.1	
Midwest	18.9	46.3	4.1		48.1	40.3	25.2	
Urban Hospital	100.0	100.0	94.6	0.040	100.0	83.9	95.6	0.001
Teaching Hospital	100.0	100.0	63.3	0.001	100.0	75.8	53.5	0.001
High Volume Hospital	52.7	46.3	3.4	0.001	82.5	33.9	4.4	0.001
Pancreas Resection								
Geographic Region				0.001				0.008
Northeast	8.7	27.3	20.0		27.9	20.4	34.2	
South	65.8	60.0	57.9		28.9	37.9	39.2	
West	6.8	12.7	12.4		29.9	20.4	11.4	
Midwest	18.6	0.0	9.7		13.2	21.4	15.2	
Urban Hospital	100.0	100.0	97.2	0.049	94.9	96.1	100.0	NS
Teaching Hospital	95.7	70.9	55.9	0.001	82.2	80.6	63.3	0.002
High Volume Hospital	75.8	3.6	4.1	0.001	46.2	20.4	2.5	0.001
Gastrectomy								
Geographic Region				0.002				0.041
Northeast	33.0	31.0	29.7		36.6	37.6	29.8	
South	62.0	47.7	57.0		46.2	38.2	46.6	
West	0.0	8.4	7.4		9.7	8.1	11.6	
Midwest	5.0	12.9	5.9		7.5	16.2	12.0	
Urban Hospital	100.0	94.2	89.8	0.001	100.0	96.0	90.5	0.001
Teaching Hospital	92.0	70.3	46.0	0.001	88.7	56.6	45.7	0.001
High Volume Hospital	87.0	27.1	15.6	0.001	73.7	26.6	18.8	0.001
Lung Lobectomy								
Geographic Region				0.001				0.001
Northeast	0.0	32.9	24.6		30.9	30.5	20.5	
South	76.8	43.3	60.6		68.9	43.4	46.7	
West	0.0	0.0	9.7		0.0	12.7	14.9	
Midwest	23.2	23.8	5.1		0.1	13.3	17.8	
Urban Hospital	100.0	100.0	94.5	0.001	89.8	97.0	93.9	0.001
Teaching Hospital	92.0	78.8	47.0	0.001	85.4	66.2	38.4	0.001
High Volume Hospital	78.3	43.6	11.7	0.001	93.1	43.7	13.2	0.001
Other Procedures								
CABG								
Geographic Region				0.001				0.001
Northeast	30.3	24.1	15.0		11.0	28.8	12.0	
South	58.4	57.6	56.6		70.7	46.1	59.5	
West	3.4	6.6	15.9		9.8	9.5	14.2	
Midwest	7.9	11.7	12.5		8.5	15.6	14.2	
Urban Hospital	99.0	96.4	99.8	0.001	100.0	97.4	95.7	0.001
Teaching Hospital	54.9	63.6	75.0	0.001	86.3	47.8	43.1	0.001
High Volume Hospital	50.1	26.9	27.7	0.001	49.5	9.9	18.1	0.001
CEA								
Geographic Region				0.001				0.001
Northeast	19.9	24.2	23.9		20.1	22.2	24.2	
South	72.4	58.3	54.1		48.0	50.8	51.0	
West	3.8	7.5	10.7		6.5	12.8	10.9	
Midwest	3.9	10.1	11.3		25.4	14.2	13.9	
Hospital Location	94.3	90.2	90.4	0.001	97.4	87.5	92.6	0.001
Teaching Hospital	45.1	44.0	40.2	0.001	49.3	32.9	38.6	0.001
High Volume Hospital	55.5	26.3	18.0	0.001	34.5	19.1	9.3	0.001
Thyroidectomy								
Geographic Region				0.001				0.001
Northeast	63.4	37.0	25.6		41.4	34.8	22.4	
South	33.0	51.4	57.3		19.5	37.9	47.0	
West	0.0	9.0	10.9		17.2	13.0	14.4	
Midwest	3.6	2.7	6.2		22.0	14.4	16.2	
Urban Hospital	99.8	97.6	85.9		99.9	97.5	87.9	0.001
Teaching Hospital	93.7	63.5	45.6	0.001	62.8	49.7	38.6	0.001
High Volume Hospital	75.0	23.1	8.1	0.001	74.3	23.0	17.8	0.001

± *values given as percentage*
NS = not significant
* Based on Chi squared analyses; signifiance set at α=0.05

Patient Characteristics

A total of 250,949 patients were identified in the HCUP-NIS 1999 or 2005 database who underwent a procedure in this study (Table 6). Forty two percent (n=105,868) of patients were not included in further analyses because they did not have an associated surgeon identifier (Table 5). These patients were found not to have significant demographic or clinical differences compared to patients who had a surgeon identifier.

Table 5: Patient and Surgeon Totals

		Colectomy	Esophagectomy	Pancreatectomy	Gastrectomy	Lobectomy	CABG	CEA	Thyroidectomy
Year 1999	Patients With Surgeon ID	14152	262	361	1016	4411	35887	16741	5427
	Patients Missing Surgeon ID	10174	314	264	852	3150	28006	10627	4167
	% Missing Surgeon ID	**41.8**	**54.5**	**42.2**	**45.6**	**41.7**	**43.8**	**38.8**	**43.4**
	Unique Surgeon Identifiers	2851	128	179	704	766	970	1572	1600
Year 2005	Patients With Surgeon ID	12611	381	379	919	5168	26167	14105	7094
	Patients Missing Surgeon ID	9851	253	333	723	3573	19222	9554	4805
	% Missing Surgeon ID	**43.9**	**39.9**	**46.8**	**44.0**	**40.9**	**42.3**	**40.4**	**40.4**
	Unique Surgeon Identifiers	2329	116	142	541	674	959	1232	1467

For the oncologic procedures, high- and low-volume surgeons operated on an equal proportion of elderly patients (those aged >65 years) in both years for colectomy, esophagectomy, pancreas resection, and lung lobectomy; for gastrectomy, high-volume surgeons operated less frequently on the elderly than low-volume surgeons in 1999 (52% vs. 67% $p<0.002$ for gastrectomy), but this difference narrowed by 2005 (56.5% vs. 63.6% p=NS for gastrectomy). For vascular procedures CABG and CEA, high- and low-volume surgeons operated on an equal proportion of elderly patients.

For all procedures except gastrectomy and CABG, high- and low-volume surgeons operated on an equal share of female patients in both time periods. For gastrectomy in 1999, only 27% of patients seen by high-volume surgeons were female compared to 41% by low-volume surgeons ($p<0.005$), but this difference narrowed to similar values by 2005. For CABG, female patients made up the minority of surgeons' practices in both years. Low-volume surgeon practices made up the greatest proportion of females in 1999; this switched to high-volume surgeons by 2005.

In 1999, high-volume surgeons more often cared for patients in the highest annual income group (≥$59,000) for all procedures except CEA; this pattern dissipated between surgeon-volume groups by 2005 for gastrectomy, lung lobectomy, CABG, and thyroidectomy.

In both years, high-volume surgeons saw a higher proportion of patients with private HMO insurance compared to low-volume surgeons for colectomy (34% vs. 30% $p<0.001$ in 1999; 35% vs. 30% in 2005), gastrectomy (51% vs. 31% $p<0.004$ in 1999; 40% vs. 29% $p<0.009$ in 2005), lung lobectomy (39% vs. 35% p=NS in 1999; 46% vs. 34% $p<0.001$ in 2005), and thyroidectomy (81% vs. 63% $p<0.001$ in 1999; 73% vs. 60% $p<0.001$ in 2005). Both high- and low- surgeon volume groups saw equal proportions of patients with private HMO insurance in both years for esophagectomy and pancreas resection; in CABG or CEA, however, high-volume surgeons saw these patients less often compared to medium- or low-volume surgeons.

Table 6: Patient Characteristics According to Surgeon Volume by Year ±

Calander Year	1999				2005			
Surgeon Volume Cohort	High	Med	Low	p value*	High	Med	Low	p value*
Oncologic Procedures								
Colectomy								
Number of Patients	2096	2851	9204		2060	3042	7507	
Age ≥65	67.1	73.3	70.0	0.001	64.6	65.9	66.2	NS
Female sex	48.1	50.5	50.3	NS	50.3	50.7	50.5	NS
Household income ≥ $59,000	33.7	24.9	27.6	0.001	30.6	27.0	22.5	0.001
Primary payer private HMO	33.8	29.0	29.6	0.001	34.7	32.9	30.1	0.001
Non-white race	18.5	14.0	15.8	0.001	15.5	15.4	21.1	0.001
Charlson comorbidity ≥3	44.3	46.0	46.0	NS	40.1	43.1	44.5	0.002
Non-routine admission	12.5	15.9	20.9	0.001	11.7	16.9	23.1	0.001
Esophagectomy								
Number of Patients	74	41	147		159	62	159	
Age ≥65	44.6	48.8	47.6	NS	53.1	54.8	44.7	NS
Female sex	16.2	19.5	19.0	NS	20.0	17.7	14.5	NS
Household income ≥ $59,000	34.7	17.5	30.5	NS	23.6	13.6	16.7	NS
Primary payer private HMO	48.6	43.9	44.2	NS	47.5	40.3	39.6	NS
Non-white race	3.3	20.0	19.3	0.039	2.7	13.3	13.7	0.001
Charlson comorbidity ≥3	35.1	34.1	40.1	NS	33.1	32.3	35.8	NS
Non-routine admission	27.0	0.0	8.5	0.001	1.3	0.0	5.7	0.021
Pancreas Resection								
Number of Patients	161	55	145		197	103	78	
Age ≥65	60.9	70.9	56.6	NS	61.9	54.4	54.4	NS
Female sex	50.9	52.7	48.3	NS	50.3	48.5	49.4	NS
Household income ≥ $59,000	40.3	27.1	26.2	NS	30.4	21.8	23.0	NS
Primary payer private HMO	41.6	32.7	40.3	NS	30.4	21.8	23.0	NS
Non-white race	8.3	24.4	24	0.001	17.7	20.8	31.9	NS
Charlson comorbidity ≥3	74.5	70.9	60.7	0.031	59.4	57.3	64.6	NS
Non-routine admission	31.9	14.3	24.3	0.039	10	10.8	24.4	0.005
Gastrectomy								
Number of Patients	100	155	761		186	173	560	
Age ≥65	52.0	61.3	67.4	0.002	56.5	56.6	63.6	NS
Female sex	27.0	31.2	40.7	0.005	39.2	35.3	42.5	NS
Household income ≥ $59,000	51.6	27.7	27.6	0.001	24.2	27.1	21.9	NS
Primary payer private HMO	51.0	28.6	31.0	0.004	39.5	30.6	29.2	0.009
Non-white race	23.3	32.1	31.1	NS	34.2	37.7	36.7	0.001
Charlson comorbidity ≥3	67.0	62.6	58.2	NS	48.9	52.6	60.2	0.014
Non-routine admission	22.0	19.1	21.2	NS	9.7	12.7	21.6	0.001
Lung Lobectomy								
Number of Patients	314	690	3407		734	1114	3319	
Age ≥65	58.3	63.8	63.4	NS	61.6	63.7	62.0	NS
Female sex	48.4	47.7	45.1	NS	50.3	49.7	50.2	NS
Household income ≥ $59,000	44.4	32.8	28.5	0.001	14.6	33.1	22.8	0.001
Primary payer private HMO	39.0	32.9	35.0	NS	45.6	30.2	33.6	0.001
Non-white race	12.0	9.5	13.6	0.001	3.3	11.1	13.2	0.001
Charlson comorbidity ≥3	70.7	76.7	78.0	0.012	72.2	80.1	79.7	0.001
Non-routine admission	33.4	4.6	6.3	0.001	0.5	2.3	4.0	0.001
Other Procedures								
CABG								
Number of Patients	14726	15990	5167		5467	13633	6992	
Age ≥65	58.9	56.4	54.6	0.001	54.4	56.2	50.7	0.001
Female sex	28.4	28.0	31.2	0.001	28.8	27.3	27.5	0.118
Household income ≥ $59,000	31.7	28.0	24.5	0.001	17.9	20.6	16.7	0.001
Primary payer private HMO	36.6	38.4	36.2	0.001	36.3	34.3	38.6	0.001
Non-white race	11.9	10.5	17.1	0.001	16.4	18.8	23.0	0.001
Charlson comorbidity ≥3	11.4	11.3	10.4	NS	14.6	13.7	14.6	NS
Non-routine admission	41.6	43.8	51.7	0.001	43.4	39.7	43.7	0.001
CEA								
Number of Patients	4420	10440	1881		3014	9750	1340	
Age ≥65	77.7	77.6	75.2	0.023	75.9	75.7	72.4	0.018
Female sex	43.2	43.0	43.6	NS	42.9	43.1	43.1	NS
Household income ≥ $59,000	21.6	27.9	24.6	0.001	22.0	21.0	20.3	0.007
Primary payer private HMO	21.9	23.9	26.0	0.001	21.5	22.2	26.0	0.001
Non-white race	7.4	6.0	12.2	0.001	6.5	9.6	13.6	0.001
Charlson comorbidity ≥3	13.1	12.9	13.9	NS	15.1	15.2	16.1	NS
Non-routine admission	9.6	11.9	19.8	0.001	7.5	10.0	15.5	0.001
Thyroidectomy								
Number of Patients	1218	1012	3197		1789	2100	3204	
Age ≥65	14.1	19.4	23.5	0.001	19.8	22.4	24.7	0.001
Female sex	82.4	81.6	82.0	NS	78.8	81.2	79.4	NS
Household income ≥ $59,000	55.7	38.3	29.9	0.001	38.3	27.4	26.4	0.001
Primary payer private HMO	80.9	70.5	63.2	0.001	72.8	62.9	60.0	0.001
Non-white race	24.1	22.7	26.2	0.001	25.2	30.3	28.8	0.001
Charlson comorbidity ≥3	7.1	6.8	8.0	NS	7.9	7.9	8.0	NS
Non-routine admission	14.0	0.7	4.9	0.001	0.5	3.0	3.1	0.001

± *except for number of patients, all values given as percentage of patients within volume category*

NS = not significant

* Based on Chi squared analyses; signifiance set at α=0.05

The ethnic makeup of patients seen by each surgeon volume group varied widely between procedure and year. Differences in the proportion of non-white patients seen by low- and high-volume surgeon groups were most pronounced for esophagectomy (19% for low-volume vs. 3% for high-volume $p<0.039$ in 1999; 14% vs. 3% $p<0.001$ in 2005), CABG (17% vs. 12% <0.001 in 1999; 23% vs. 16% $p<0.001$ in 2005), and CEA (12% vs. 7% $p<0.001$ in 1999; 14% vs. 7% $p<0.001$ in 2005). Of note, for esophagectomy and CEA, the percentage of non-white patients seen by high-volume surgeons remained constant in both time periods. For lung lobectomy, the proportion of non-white patients seen by high-volume surgeons fell dramatically over time; whereas 12% of patients seen by high-volume surgeons for this procedure were non-white in 1999, only 3% were in 2005. The opposite was true for pancreas resection; in 1999, 8.3% of patients seen by high-volume surgeons were non-white compared 18% in 2005.

Charlson comorbity scores for patients in the high-volume surgeons group were not significantly higher than low-volume surgeons for any procedure except pancreas resection in 1999. Differences were statistically non-significant across all surgeon-volume groups in both years for esophagectomy, CABG, CEA, and thyroidectomy. For colectomy and gastrectomy, there was an increase in the proportion of patients with a Charlson comorbidity score ≥3 seen by low-volume surgeons from 1999 to 2005.

High-volume surgeons more often saw patients who were admitted to the hospital in a non-routine fashion in 1999 for pancreas resection, gastrectomy, lung lobectomy, esophagectomy, and thyroidectomy. This changed by 2005, when low-volume surgeons were instead the group whose practice made up the greatest portion of patients admitted in a non-routine fashion. For colectomy and CEA, low-volume surgeons had the greatest proportion of non-routinely admitted patients in both years compared to high-volume surgeons (for colectomy 21% vs. 13% $p<0.001$ in 1999 and 23% vs. 12% $p<0001$ in 2005; for CEA 20% vs. 10% $p<0.001$ in 1999 and 15% vs. 8% $p<0.001$ in 2005). For CABG, the proportion of patients seen in a non-routine fashion shifted away from low- to high-volume surgeons between 1999 and 2005 (52% vs. 42% $p<0.001$ in 1999 and 44% vs. 43% $p<0.001$ in 2005).

For all procedures in 1999, a majority of high-volume surgeons performed their operations at a high-volume hospital ($p<0.001$). In 2005, there was a decline for colectomy (59% in 1999 to 46% in 2005), pancreatectomy (76% in 1999 to 46% in 2005), and CEA (56% in 1999 to 35% in 2005). Of note, both esophagectomy and lung-lobectomy had a large increase in the proportion of high-volume surgeons operating at a high-volume hospital.

Surgeon Volume Shifts

Overall, there was a significant increase ($p<0.001$) in high-volume surgeons share between 1999 and 2005 for all procedures except CABG and CEA (Table 7). The most dramatic relative increases were seen for gastrectomy (106%), lung lobectomy(100%), and esophagectomy(49%). The percentage of patients that were operated by each of the three surgeon volume groups is represented graphically in appendix 2.

For all procedures, medium-volume surgeons gained patient shares between 1999 and 2005; this was most dramatic for pancreatectomy (79%) and thyroidectomy (58%).

Low-volume surgeon share decreased for all procedures except CABG. The most dramatic relative movements away from the low-volume surgeons were for pancreas resection (-49%) and esophagectomy (-26%).

Table 7: Surgeon Volume Shares by Year

High Volume Surgeon Share (%)

	1999	2005	% Change
Oncologic			
Colectomy	14.8	16.3	10.1
Esophagectomy	28.2	42.0	48.9
Pancreas Resection	44.6	52	16.6
Gastrectomy	9.8	20.2	106.1
Lung Lobectomy	7.1	14.2	100.0
Other			
CABG	41	21.1	-48.5
CEA	26.4	21.4	-18.9
Thyroidectomy	22.4	25.2	12.5

Medium Volume Surgeon Share (%)

	1999	2005	% Change
Oncologic			
Colectomy	20.2	24.2	19.8
Esophagectomy	15.7	16.3	3.8
Pancreas Resection	15.2	27.2	78.9
Gastrectomy	15.3	18.9	23.5
Lung Lobectomy	15.7	21.6	37.6
Other			
CABG	44.6	52.2	17.0
CEA	62.4	69.1	10.7
Thyroidectomy	18.7	29.6	58.3

Low Volume Surgeon Share (%)

	1999	2005	% Change
Oncologic			
Colectomy	65	59.5	-8.5
Esophagectomy	56.1	41.7	-25.7
Pancreas Resection	40.2	20.8	-48.3
Gastrectomy	74.9	60.9	-18.7
Lung Lobectomy	77.2	64.2	-16.8
Other			
CABG	14.4	26.7	85.4
CEA	11.2	9.5	-15.2
Thyroidectomy	58.9	45.2	-23.3

The absolute number of high-volume surgeons increased most dramatically for pancreas resection (11 in 1999, 23 in 2005), and decreased most dramatically for CABG (74 in 1999, 30 in 2005) (Table 8). The number of medium-volume surgeons almost doubled over time for pancreatectomy and thyroidectomy.

Table 8: Number of Surgeons

		Colectomy	Esophagectomy	Pancreatectomy	Gastrectomy	Lobectomy	CABG	CEA	Thyroidectomy
Year 1999	High Volume N	68	4	11	15	5	74	53	24
	Medium Volume N	191	5	23	48	22	169	608	67
	Low Volume N	2592	119	145	641	738	728	910	1509
Year 2005	High Volume N	72	7	23	23	8	30	43	37
	Medium Volume N	205	8	40	49	36	153	530	138
	Low Volume N	2052	101	79	469	630	776	659	1292

Unadjusted Patient Outcomes

Unadjusted overall mortality rates improved for all procedures except pancreas resection between 1999 and 2005. For this procedure, mortality rates remained similar. Endocrine complication rates increased slightly for thyroidectomy from 6.1 to 7.0 ($p<.006$) between time periods. LOS remained relatively stable for all procedures, with only slight differences noted for esophagectomy (increase from 15.4 to 16.3 p=NS) and gastrectomy, (13.6 to 14.4 $p=.043$).

Mortality rates between for high-volume surgeons were lower for all procedures compared to their low-volume surgeon counterparts in 1999 (Table 9). This was especially pronounced for colectomy (1.3 vs. 3.5 $p<.001$), esophagectomy (0 vs. 6.8

p=.041), and pancreas resection (2.5 vs. 10.3 p=.016). Complication rates for thyroidectomy were also lower for high-volume surgeons (2.5 vs. 7.1 p<0.001). These differences between high- and low-volume surgeons dissipated over time, however. For example, for colectomy, high-volume surgeons had a 1.3% mortality rate in 1999 and a 2.3% rate in 2005, whereas low-volume surgeons had a decrease in mortality rate from 3.5% in 1999 to 2.8% in 2005. Low-volume surgeons had improved outcomes in 2005 compared to 1999 for pancreas resection, lung lobectomy, CABG, and CEA.

LOS was lower for high- compared to low-volume surgeons for all procedures in both years. Medium-volume surgeons had LOS values which were between high- and low-volume surgeons for all procedures except gastrectomy (in this procedure, medium-volume surgeons had the longest LOS in both 1999 and 2005).

Table 9: Unadjusted Outcomes According to Surgeon Volume by Year*

Calander Year	1999				2005			
Surgeon Volume Cohorts	High	Med	Low	p value*	High	Med	Low	p value*
Oncologic Procedures								
Colectomy								
Mortality (%)	1.3	2.6	3.5	0.001	2.3	2.2	2.8	NS
Mean length of stay (d)	8.5	9.4	10.0	0.001	8.1	9.1	9.7	0.001
(95% CI)	(8.3-8.7)	(9.2-9.6)	(9.8-10.1)		(7.9-8.4)	(8.9-9.3)	(9.5-9.9)	
Esophagectomy								
Mortality (%)	0.0	9.8	6.8	0.041	0.6	6.5	8.8	0.003
Mean length of stay (d)	11.2	14.3	17.4	0.001	12.5	16.1	18.5	0.002
(95% CI)	(9.0-13.4)	(11.1-17.5)	(15.4-19.3)		(10.7-14.3)	(12.0-20.2)	(15.7-21.4)	
Pancreas Resection								
Mortality (%)	2.5	5.5	10.3	0.016	2.5	5.8	9.0	NS
Mean length of stay (d)	13.3	18.1	20.6	0.001	13.6	14.9	24.1	0.001
(95% CI)	(11.9-14.6)	(15.6-20.6)	(18.1-23.1)		(12.2-15.1)	(13.0-16.7)	(19.8-28.5)	
Gastrectomy								
Mortality (%)	4.0	8.4	6.6	NS	3.8	5.2	6.8	NS
Mean length of stay (d)	11.4	14.7	14.0	0.043	13.0	16.5	14.8	0.038
(95% CI)	(10.0-12.8)	(12.9-16.6)	(13.2-14.8)		(11.4-14.5)	(13.8-19.1)	(13.8-15.7)	
Lung Lobectomy								
Mortality (%)	2.5	2.8	3.9	NS	1.4	3.4	3.3	0.017
Mean length of stay (d)	7.1	8.0	9.1	0.001	6.4	8.3	8.9	0.001
(95% CI)	(6.5-7.8)	(7.7-8.4)	(8.9-9.4)		(6.0-6.8)	(7.8-8.7)	(8.7-9.2)	
Other Procedures								
CABG								
Mortality (%)	2.4	2.7	4.1	0.001	2.0	2.2	2.3	NS
Mean length of stay (d)	8.9	8.8	9.7	0.001	9.1	9.2	9.6	0.001
(95% CI)	(8.8-9.0)	(8.7-8.9)	(9.5-9.9)		(8.9-9.3)	(9.1-9.3)	(9.4-9.7)	
CEA								
Mortality (%)	0.5	0.5	1.0	0.010	0.2	0.4	0.4	NS
Mean length of stay (d)	2.7	3.1	4.5	0.001	2.3	2.7	3.9	0.001
(95% CI)	(2.6-2.8)	(3.0-3.2)	(4.2-4.7)		(2.3-2.6)	(2.6-2.8)	(3.7-4.2)	
Thyroidectomy								
Endocrine Complications (%)	2.5	6.1	7.1	0.001	4.9	8.9	7.9	0.001
Mean length of stay (d)	1.4	1.8	2.4	0.001	1.3	2.4	2.3	0.001
(95% CI)	(1.3-1.5)	(1.7-1.9)	(2.1-2.7)		(1.3-1.4)	(2.1-2.6)	(2.1-2.4)	

NS = not significant; CI indicates confidence interval

* Based on Chi squared analyses for mortality and analysis of variance for LOS; signifiance set at α=0.05

Table 10: Adjusted Outcomes for Low Volume Surgeons±

Oncologic Procedures	Calander Year	1999	p value*	2005	p value*
Colectomy					
	In-Hospital Mortality Adjusted OR	2.2 (1.4-3.3)	0.001	1.0 (0.7-1.4)	NS
	Estimated Increase in Length of Stay (d)	1.1 (0.7-1.4)	0.001	0.8 (0.4-1.1)	0.001
Esophagectomy					
	In-Hospital Mortality Adjusted OR	10 (-9.0-20.0)	NS	3.8 (0.2-60.8)	NS
	Estimated Increase in Length of Stay (d)	5.0 (1.4-8.5)	0.001	5.3 (0.6-10.0)	0.05
Pancreas Resection					
	In-Hospital Mortality Adjusted OR	5.8 (1.0-34.8)	NS	2.8 (0.8-10.4)	NS
	Estimated Increase in Length of Stay (d)	7.6 (3.4-11.7)	0.001	9.5 (5.2-13.8)	0.001
Gastrectomy					
	In-Hospital Mortality Adjusted OR	0.7 (0.2-2.4)	NS	0.8 (0.3-2.3)	NS
	Estimated Increase in Length of Stay (d)	1.6 (-1.0-4.2)	NS	0.8 (-1.6-3.1)	NS
Lung Lobectomy					
	In-Hospital Mortality Adjusted OR	1.6 (0.7-3.9)	NS	1.5 (0.7-3.3)	NS
	Estimated Increase in Length of Stay (d)	2.8 (2.0-3.7)	0.001	1.7 (1.0-2.4)	0.001
Other Procedures					
CABG					
	In-Hospital Mortality Adjusted OR	1.5 (1.2-1.8)	0.001	1.1 (0.8-1.5)	NS
	Estimated Increase in Length of Stay (d)	1.0 (0.7-1.2)	0.001	1.0 (0.6-1.3)	0.001
CEA					
	In-Hospital Mortality Adjusted OR	1.5 (0.7-2.8)	NS	1.7 (0.5-5.7)	NS
	Estimated Increase in Length of Stay (d)	1.4 (1.2-1.5)	0.001	0.9 (0.7-1.1)	0.001
Thyroidectomy					
	Endocrine Complications Adjusted OR	1.7 (1.0-2.8)	0.05	1.1 (0.8-1.5)	NS
	Estimated Increase in Length of Stay (d)	0.8 (0.1-1.5)	0.05	0.3 (0.1-0.6)	0.05

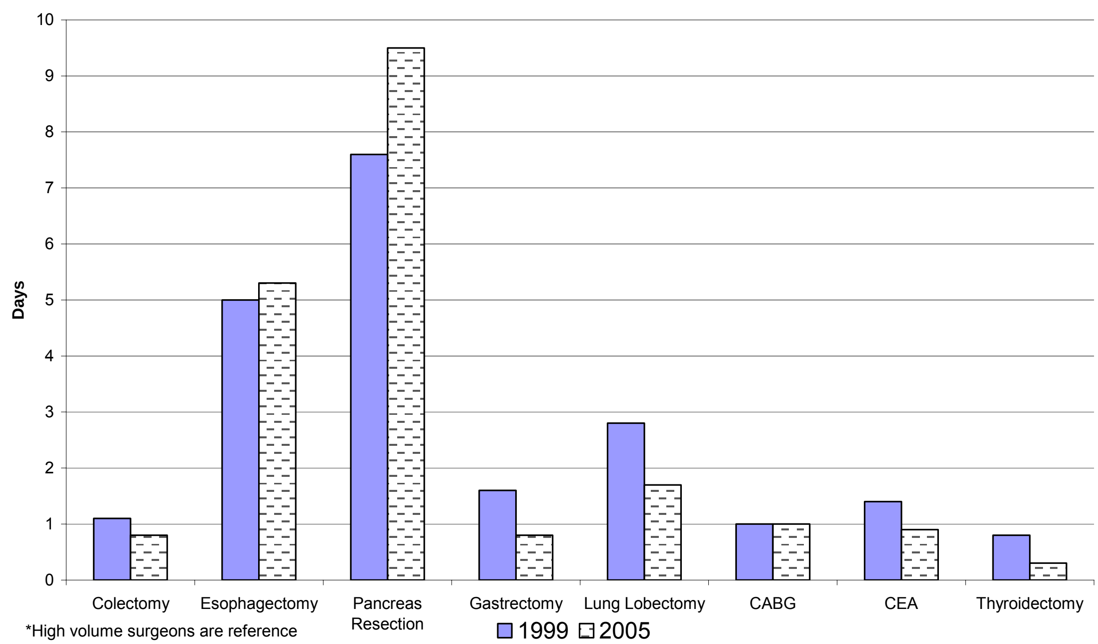
±reference is high volume surgeon cohort : adjustments made for patient and provider characteristics
OR = Odds Ratio (95% CI)
*signifiance set at α=0.05

Adjusted Patient Outcomes

Low-volume surgeons had statistically similar mortality rates compared to high-volume surgeons for esophagectomy, gastrectomy, lung-lobectomy, and pancreatectomy after adjustment for patient and provider characteristics in 1999, and all procedures by 2005 (Table 10). For thyroidectomy, endocrine complication rates were higher for high- compared to low-volume surgeons in 1999, but statistically similar by 2005.

Low-volume surgeons had a significantly longer inpatient LOS compared to high-volume surgeons for all procedures even after adjustment in both years except gastrectomy in 1999. These differences attenuated slightly over time for colectomy, gastrectomy, lung lobecomy, CEA, and thyroidectomy (Table 10 & Figure 1).

Figure 1: Increased Length of Stay by Low-Volume Surgeons (adjusted value)*



*High volume surgeons are reference

Discussion

Referral Shifts

This is the first study to our knowledge to demonstrate changes in surgeon volume referral patterns over time for procedures shown in the literature to have a strong surgeon volume-outcome association. For most procedures, the percentage of patients seeking care from a high-volume surgeon increased significantly between 1999 and 2005. For CEA and CABG, there was a decrease in high-volume surgeon share over time. This is likely related to the 27% decline in overall procedure volume for CABG and 16%

decrease for CEA, suggesting the potential need to lower what defines a high-volume surgeon for these procedures (Table 5).

The increased share of patients seeking care from a high-volume surgeon may reflect an increased public awareness of potential benefits. [5] Physicians may also be sending more patients to high-volume surgeons because of mounting evidence in the scholarly literature supporting this practice throughout the last decade.[5]

Referral patterns to high-volume surgeons are not likely related to Leapfrog hospital referral policies. Of the eight procedures analyzed in this study, only three have Leapfrog hospital volume standards. These include esophagectomy, CABG, and CEA. While high-volume surgeons predominately practice at high-volume hospitals (Table 4), this association decreased for most procedures over time. This suggests other factors may be influencing the increasing number of patients seeking care from a high-volume surgeon.

Increasingly, general surgeons are narrowing their focus of practice.[11] This is reflected by the existence of a spectrum of new fellowships that are self-designated, or society sponsored which do not lead to American Board of Medical Specialist certification. This study shows that there has been an increase in the absolute number of high-volume surgeons for all procedures. This phenomenon may be related to increasing demands of patients seeking care from high volume surgeons.[27] Thus, there are likely multiple forces contributing to the increased share of patients seeking care from high-volume surgeons.

Outcome Differences

This study shows that low-volume surgeons have higher unadjusted mortality rates than high-volume surgeons for colectomy, esophagectomy, and pancreatectomy in 1999, and esophagectomy and lobectomy in 2005. After adjustment for patient and provider characteristics, low-volume surgeons have a higher mortality rate for colectomy in 1999. By 2005, there were no differences in mortality rates (or complication rates for thyroidectomy) between high- and low-volume surgeons for any procedure. Low-volume surgeons appear to have improved clinical outcomes (mortality, or endocrine complications for thyroidectomy) over time, matching the high-volume surgeon group by 2005.

Significant differences in LOS persisted after adjustment over time for all procedures except gastrectomy in 2005. This has important implications. Low-volume surgeons may have higher post-operative complication rates, necessitating a longer hospital stay by their patients. While cost was not directly evaluated in this study, longer LOS may be related to cost [15]. Thus, high-volume surgeons may be more cost-efficient, although this would need to be validated another study.

It is unknown whether high-volume surgeons have shorter LOS because of inherent differences in surgical skill or because of superior pre- and/or post-operative surgical pathways. As Donabedian described, the factors which influence surgical outcomes can be divided theoretically into structural or process measures.[26, 27] An example of a structural measure is a high-volume surgeon’s superior intra-operative skill. Process measures include the appropriate use of pre-operative prophylactic antibiotics or peri-operative beta blockade.

For the procedures in this study, there may be components of both structure and process factors related to the increased LOS by low- compared to high-volume surgeons. High-volume surgeons may be better equipped to recognize and deal with post-operative complications. Alternatively, they may be using superior judgment when determining which patients will benefit from a given operation. For example, in pancreas resection for cancer, Maa et al. has shown that high-volume surgeons perform more cost-effective diagnostic tests than low-volume surgeons. They readily use preoperative thin cut pancreas protocol CT scans, and avoid unnecessary tests like percutaneous pancreatic biopsies.[28] The same is true for less risky procedures. While no data exist for thyroidectomy, for parathyroidectomy it has been well established that formal guidelines established by the National Institutes of Health are adhered to less often by low- compared to high-volume surgeons.[29]

Despite differences in patient demographics by surgeon volume group, patients had remarkably similar comorbidities for most procedures. This finding lends support to the notion that high-volume surgeons have patients with a shorter LOS independent of patient comorbidity, since they are not operating on a healthier group.

High-volume surgeons see patients who are disproportionately younger, wealthier, have private insurance, or are white. (Table 6) Given that few high-volume surgeons exist in the U.S., these patients may have better means of accessing these surgeons (Table 8). For thyroidectomy, there are data showing that increased age and race are independently associated with increased complication rates, costs, and LOS, especially when the procedure is performed by a low-volume surgeon.[21] This study shows that patients most likely to benefit from a shorter LOS are the same patients who are least likely to have their operations performed by a high-volume surgeon.

One goal of this study is to inform policy makers. One interpretation of our results may be the idea that surgeon-volume standards should be incorporated into policy just has been done for hospital volume. We believe it is dangerous to set policy without further studies because of concern for under-adjustment of confounders unique to individual surgeons and procedures. One concern is that there are too many patients to be cared for by the limited number high-volume surgeons in the US. Thus, surgeon-volume standards may conceivably make patient access difficult. Policies should only be established after careful analysis of their implications.

Study Limitations

The limitations to our study include those inherent in any administrative databases. This study is inherently retrospective with all the limitations known to such a study. Since we relied upon ICD-9 procedure and diagnosis codes to extract patient cases, there is a potential for coding error. We did our best to identify errors and make corrections when necessary; however, this was rare and has not been shown to be pervasive in HCUP-NIS.

Though the aim of this study was to identify referral patterns nationally, HCUP-NIS only captures a 20% sample of all US hospitals and does not include federal hospitals such as Veterans Affairs hospitals.

Another limitation inherent to HCUP-NIS is that it lacks important patient information, such as social gradients (e.g. patient education level or occupation), which conceivably could influence patients' access to high-volume surgeons or their outcomes.[30] In addition, HCUP-NIS does not contain stage of disease information, and therefore there may be some error related to adjustment for severity of illness.

Since the HCUP-NIS data in this study were a cross-sectional sample of patients in 1999 and 2005, longitudinal data were not available. Thus, distinguishing between complications and comorbidities is difficult. Our method has been validated for administrative databases, however, and has been used by others in related administrative database studies. Further, our comorbidity measurements are consistent with those in the literature.[22-25] Given that HCUP-NIS is a national sample without patient identifying information, checking the accuracy of reporting via chart review for complications and comorbidities is not possible.

Technological advances for surgical procedures may play a role in outcome differences between surgeon volume groups and are difficult to capture in HCUP-NIS. We did control for laparoscopy rates for colectomy and thoracoscopy for lung-lobectomy in our adjusted mortality and LOS outcomes. The number of surgeons who used this technology did change over time; however, its use did not affect our results.(Table 11)

Table 11: Laparosopic / Thoracoscopic Usage Rates

	1999				2005			
	High	Med	Low	p value	High	Med	Low	p value
Colectomy (%)	2.5	0.8	1.1	0.001	6.8	3.6	3.1	0.001
Lung Lobectomy (%)	1.9	6.1	4.3	0.009	5.4	6.4	6.1	NS

Lastly, we identified surgeons using unique surgeon identifiers, however, individual surgeons may have multiple identifiers if s/he practices in multiple hospitals. This is generally not thought to be a pervasive problem in HCUP-NIS.

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Appendix Attached.

Appendix 1. Procedure Inclusion & Exclusion Criteria (HCUP-NIS)

Colectomy

Primary Procedure

ICD9	CCS	
'4571 '	'78 '	MULT SEG LG BOWEL EXCIS
'4572 '	'78 '	CECECTOMY
'4573 '	'78 '	RIGHT HEMICOLECTOMY
'4574 '	'78 '	TRANSVERSE COLON RESECT
'4575 '	'78 '	LEFT HEMICOLECTOMY (Begin 1988)
'4576 '	'78 '	SIGMOIDECTOMY
'4579 '	'78 '	PART LG BOWEL EXCIS NEC
'458 '	'78 '	TOT INTRA-ABD COLECTOMY
'4849 '	'78 '	PULL-THRU RECT RESEC NEC
'485 '	'78 '	ABD-PERINEAL RECT RESECT
'4861 '	'78 '	TRANSSAC RECTOSIGMOIDECT
'4862 '	'78 '	ANT RECT RESECT W COLOST
'4863 '	'78 '	ANTERIOR RECT RESECT NEC
'4864 '	'78 '	POSTERIOR RECT RESECTION
'4866 '	'78 '	HARTMANN RESECTION RECTUM (Begin 1980, End 1988)
'4869 '	'78 '	RECTAL RESECTION NEC

Primary Diagnosis

ICD9	CCS	
'1530 '	'14 '	MAL NEO HEPATIC FLEXURE
'1531 '	'14 '	MAL NEO TRANSVERSE COLON
'1532 '	'14 '	MAL NEO DESCEND COLON
'1533 '	'14 '	MAL NEO SIGMOID COLON
'1534 '	'14 '	MALIGNANT NEOPLASM CECUM
'1535 '	'14 '	MALIGNANT NEO APPENDIX
'1536 '	'14 '	MALIG NEO ASCEND COLON
'1537 '	'14 '	MAL NEO SPLENIC FLEXURE
'1538 '	'14 '	MALIGNANT NEO COLON NEC
'1539 '	'14 '	MALIGNANT NEO COLON NOS
'1540 '		MAL NEO RECTOSIGMOID JCT
'1541 '		MALIGNANT NEOPL RECTUM

Esophagectomy

Primary Procedure

ICD9	
'4240 '	ESOPHAGECTOMY NOS
'4241 '	PARTIAL ESOPHAGECTOMY
'4242 '	TOTAL ESOPHAGECTOMY

Primary Diagnosis

ICD9	CCS	
'1500 '	'12 '	MAL NEO CERVICAL ESOPHAG
'1501 '	'12 '	MAL NEO THORACIC ESOPHAG
'1502 '	'12 '	MAL NEO ABDOMIN ESOPHAG
'1503 '	'12 '	MAL NEO UPPER 3RD ESOPH
'1504 '	'12 '	MAL NEO MIDDLE 3RD ESOPH
'1505 '	'12 '	MAL NEO LOWER 3RD ESOPH
'1508 '	'12 '	MAL NEO ESOPHAGUS NEC
'1509 '	'12 '	MAL NEO ESOPHAGUS NOS
'1510 '		MAL NEO STOMACH CARDIA
'2301 '		CA IN SITU ESOPHAGUS

Thyroidectomy

Primary Procedure

ICD9	
'062 '	UNILAT THYROID LOBECTOMY
'0631 '	EXCISION THYROID LESION
'0639 '	PART THYROIDECTOMY NEC
'064 '	COMPLETE THYROIDECTOMY
'0650 '	SUBSTERN THYROIDECT NOS
'0651 '	PART SUBSTERN THYROIDECT
'0652 '	TOT SUBSTERN THYROIDECT

Carotid Endarterectomy

Primary Procedure

ICD9	
'3812 '	HEAD & NECK ENDARTER NEC

Secondary Procedure Exclusions

ICD9	CCS	
'3500 '	'43 '	CLOSED VALVOTOMY NOS
'3501 '	'43 '	CLOSED AORTIC VALVOTOMY
'3502 '	'43 '	CLOSED MITRAL VALVOTOMY
'3503 '	'43 '	CLOSED PULMON VALVOTOMY
'3504 '	'43 '	CLOSED TRICUSP VALVOTOMY
'3510 '	'43 '	OPEN VALVULOPLASTY NOS
'3511 '	'43 '	OPN AORTIC VALVULOPLASTY
'3512 '	'43 '	OPN MITRAL VALVULOPLASTY
'3513 '	'43 '	OPN PULMON VALVULOPLASTY
'3514 '	'43 '	OPN TRICUS VALVULOPLASTY
'3520 '	'43 '	REPLACE HEART VALVE NOS
'3521 '	'43 '	REPLACE AORT VALV-TISSUE
'3522 '	'43 '	REPLACE AORTIC VALVE NEC
'3523 '	'43 '	REPLACE MITR VALV-TISSUE
'3524 '	'43 '	REPLACE MITRAL VALVE NEC
'3525 '	'43 '	REPLACE PULM VALV-TISSUE
'3526 '	'43 '	REPLACE PULMON VALVE NEC
'3527 '	'43 '	REPLACE TRIC VALV-TISSUE
'3528 '	'43 '	REPLACE TRICUSP VALV NEC
'3596 '	'43 '	PERC HEART VALVULOPLASTY (Begin 1986)
'3599 '	'43 '	OTHER HEART VALVE OPS
'3610 '	'44 '	AORTOCORONARY BYPASS NOS
'3611 '	'44 '	AORTOCOR BYPAS-1 COR ART
'3612 '	'44 '	AORTOCOR BYPAS-2 COR ART
'3613 '	'44 '	AORTOCOR BYPAS-3 COR ART
'3614 '	'44 '	AORTCOR BYPAS-4+ COR ART
'3615 '	'44 '	1 INT MAM-COR ART BYPASS
'3616 '	'44 '	2 INT MAM-COR ART BYPASS
'3617 '	'44 '	ABD-CORON ART BYPASS (Begin 1996)
'3619 '	'44 '	HRT REVAS BYPS ANAS NEC
'362 '	'44 '	ARTERIAL IMPLANT REVASC
'363 '	'44 '	HEART REVASCULARIZAT NEC (End 1998)
'3631 '	'44 '	OPEN CHEST TRANSMYO REVASC (Begin 1998)
'3632 '	'44 '	OTH TRANSMYO REVASC (Begin 1998)
'3633 '	'44 '	ENDO TRANSMYO REVASCULAR (Begin 2006)
'3634 '	'44 '	PERC TRANSMYO REVASCULAR (Begin 2006)
'3639 '	'44 '	OTHER HEART REVASC (Begin 1998)
'0066 '	'45 '	PTCA OR CORONARY ATHER (Begin 2005)
'3601 '	'45 '	PTCA-1 VESSEL W/O AGENT (Begin 1986, End 2005)
'3602 '	'45 '	PTCA-1 VESSEL WITH AGNT (Begin 1986, End 2005)
'3605 '	'45 '	PTCA-MULTIPLE VESSEL (Begin 1986, End 2005)
'3604 '	'46 '	INTRCORONRY THROMB INFUS (Begin 1986)
'3721 '	'47 '	RT HEART CARDIAC CATH
'3722 '	'47 '	LEFT HEART CARDIAC CATH
'3723 '	'47 '	RT/LEFT HEART CARD CATH
'8852 '	'47 '	RT HEART ANGIOCARDIOGRAM
'8853 '	'47 '	LT HEART ANGIOCARDIOGRAM
'8854 '	'47 '	RT & LT HEART ANGIOCARD
'8855 '	'47 '	CORONAR ARTERIOGR-1 CATH
'8856 '	'47 '	CORONAR ARTERIOGR-2 CATH
'8857 '	'47 '	CORONARY ARTERIOGRAM NEC
	'49 '	'Ot OR heart '
'3808 '		EMBOLECTOMY LEG VESSEL
'3804 '		INCISION OF AORTA
'3814 '		ENDARTERECTOMY OF AORTA
'3815 '		THORACIC ENDARTERECTOMY
'3816 '		ABDOMINAL ENDARTERECTOMY
'3818 '		ENDARTERECTOMY LEG VESL
'3835 '		THOR VESSEL RESECT/ANAST
'3836 '		ABD VESSEL RESECT/ANAST
'3837 '		ABD VEIN RESECT & ANAST
'3838 '		LEG ARTERY RESECT/ANAST
	'52 '	AORTA RESECTION & ANAST
	'52 '	RESECT ABDM AORTA W REPL (Begin 1986)
	'52 '	EXCISION OF AORTA
	'52 '	ENDOVASCULAR IMPLANT IN ABDM AORTA (Begin 2000)
	'52 '	ENDO IMP GRFT THOR AORTA (Begin 2005)
	'52 '	OTHER ENDOVASCULAR REPAIR OF ANEURYSM (Begin 2000)
	'50 '	EXTRACORPOREAL CIRCULAT
	'50 '	HYPOTHERMIA W OPEN HEART
	'50 '	CARDIOPLEGIA
	'50 '	INTRAOP CARDIAC PACEMAK
	'50 '	EXTRACORPOREAL MEMB OXY (Begin 1988)
	'50 '	PER CARDIOPULMON BYPASS (Begin 1990)

Primary Procedure

ICD9

'3610 '	AORTOCORONARY BYPASS NOS
'3611 '	AORTOCOR BYPAS-1 COR ART
'3612 '	AORTOCOR BYPAS-2 COR ART
'3613 '	AORTOCOR BYPAS-3 COR ART
'3614 '	AORTCOR BYPAS-4+ COR ART
'3615 '	1 INT MAM-COR ART BYPASS
'3616 '	2 INT MAM-COR ART BYPASS
'3617 '	ABD-CORON ART BYPASS (Begin 1996)
'3619 '	HRT REVAS BYPS ANAS NEC
'362 '	ARTERIAL IMPLANT REVASC

Secondary Procedure Exclusions

CCS

'43 '	CLOSED VALVOTOMY NOS
'43 '	CLOSED AORTIC VALVOTOMY
'43 '	CLOSED MITRAL VALVOTOMY
'43 '	CLOSED PULMON VALVOTOMY
'43 '	CLOSED TRICUSP VALVOTOMY
'43 '	OPEN VALVULOPLASTY NOS
'43 '	OPN AORTIC VALVULOPLASTY
'43 '	OPN MITRAL VALVULOPLASTY
'43 '	OPN PULMON VALVULOPLASTY
'43 '	OPN TRICUS VALVULOPLASTY
'43 '	REPLACE HEART VALVE NOS
'43 '	REPLACE AORT VALV-TISSUE
'43 '	REPLACE AORTIC VALVE NEC
'43 '	REPLACE MITR VALV-TISSUE
'43 '	REPLACE MITRAL VALVE NEC
'43 '	REPLACE PULM VALV-TISSUE
'43 '	REPLACE PULMON VALVE NEC
'43 '	REPLACE TRIC VALV-TISSUE
'43 '	REPLACE TRICUSP VALV NEC
'43 '	PERC HEART VALVULOPLASTY (Begin 1986)
'43 '	OTHER HEART VALVE OPS
'49 '	PAPILLARY MUSCLE OPS
'49 '	CHORDAE TENDINEAE OPS
'49 '	ANNULOPLASTY
'49 '	INFUNDIBULECTOMY
'49 '	TRABECUL CARNEAE CORD OP
'49 '	TISS ADJ TO VALV OPS NEC
'49 '	ENLARGE EXISTING SEP DEF
'49 '	CREATE SEPTAL DEFECT
'49 '	PROSTH REP HRT SEPTA NOS
'49 '	PROS REP ATRIAL DEF-OPN
'49 '	PROS REPAIR ATRIA DEF-CL
'49 '	PROST REPAIR VENTRIC DEF
'49 '	PROS REP ENDOCAR CUSHION
'49 '	PROS REP VENTRC DEF-CLOS (Begin 2006)
'49 '	GRFT REPAIR HRT SEPT NOS
'49 '	GRAFT REPAIR ATRIAL DEF
'49 '	GRAFT REPAIR VENTRIC DEF
'49 '	GRFT REP ENDOCAR CUSHION
'49 '	HEART SEPTA REPAIR NOS
'49 '	ATRIA SEPTA DEF REP NEC
'49 '	VENTR SEPTA DEF REP NEC
'49 '	ENDOCAR CUSHION REP NEC
'49 '	TOT REPAIR TETRAL FALLOT
'49 '	TOTAL REPAIR OF TAPVC
'49 '	TOT REP TRUNCUS ARTERIOS
'49 '	TOT COR TRANSPOS GRT VES (Begin 1988)
'49 '	INTERAT VEN RETRN TRANSP
'49 '	CONDUIT RT VENT-PUL ART
'49 '	CONDUIT LEFT VENTR-AORTA
'49 '	CONDUIT ARTIUM-PULM ART
'49 '	HEART REPAIR REVISION
'49 '	OTHER HEART SEPTA OPS
'49 '	REM OBSTR NOS (Begin 1986, End 1991)
'49 '	OPEN CORONRY ANGIOPLASTY (Begin 1986)
'49 '	(OTH)REM COR ART OBST(NEC) (Begin 1986)
'49 '	HEART ANEURYSM EXCISION
'49 '	EXC(/DEST) OTH HRT LESION (Begin 1988)
'49 '	CATH ABLATION LES HEART (Begin 1988)
'49 '	PARTIAL VENTRICULECTOMY (Begin 1997)
'49 '	HEART & PERICARD REPAIR
'49 '	IMPL CARDIAC SUPPORT DEV (Begin 2005)
'49 '	HEART/PERICARD REPR NEC (Begin 2005)
'49 '	IMPLANTATION OF TOTAL REPLACEMENT HEART SYST (Begin 200
'49 '	REPLACEMENT OR REPAIR OF THORACIC UNIT OF TO (Begin 200
'49 '	REPLACEMENT OR REPAIR OF OTHER IMPLANTABLE C (Begin 200
'49 '	IMPLANT HRT ASST SYS NEC
'49 '	REPLACE HRT ASSIST SYST
'49 '	REMOVE HEART ASSIST SYS
'49 '	IMPL EXTERN HEART ASSIST (Begin 1995)
'49 '	IMPL INTERN HEART ASSIST (Begin 1995)
'49 '	IMPLANT CARDIOMYOSTIM SYS (Begin 1998)
'49 '	PERCUTAN HRT ASSIST SYST (Begin 2004)
'49 '	INS LEFT ATR APPEND DEV (Begin 2004)
'49 '	OTHER HEART/PERICARD OPS
'52 '	AORTA RESECTION & ANAST
'52 '	RESECT ABDM AORTA W REPL (Begin 1986)
'52 '	EXCISION OF AORTA
'52 '	ENDOVASCULAR IMPLANT IN ABDM AORTA (Begin 2000)
'52 '	ENDO IMP GRFT THOR AORTA (Begin 2005)

'52 '   OTHER ENDOVASCULAR REPAIR OF ANEURYSM (Begin 2000)

Pancreas Resection

Principal Procedure

ICD9	
'526 '	TOTAL PANCREATECTOMY
'527 '	RAD PANCREATICODUODENECT

Primary Diagnosis

ICD9	CCS	
'1570 '	'17	' MAL NEO PANCREAS HEAD
'1571 '	'17	' MAL NEO PANCREAS BODY
'1572 '	'17	' MAL NEO PANCREAS TAIL
'1573 '	'17	' MAL NEO PANCREATIC DUCT
'1574 '	'17	' MAL NEO ISLET LANGERHANS
'1578 '	'17	' MALIG NEO PANCREAS NEC
'1579 '	'17	' MALIG NEO PANCREAS NOS

Gastrectomy

Principal Procedure

ICD9	CCS	
'435 '	'74 '	PROXIMAL GASTRECTOMY
'436 '	'74 '	DISTAL GASTRECTOMY
'437 '	'74 '	PART GASTREC W JEJ ANAST
'4381 '	'74 '	PART GAST W JEJ TRANSPOS
'4389 '	'74 '	PARTIAL GASTRECTOMY NEC
'4391 '	'74 '	TOT GAST W INTES INTERPO
'4399 '	'74 '	TOTAL GASTRECTOMY NEC

Primary Diagnosis

ICD9	CCS	
'1510 '	'13	' MAL NEO STOMACH CARDIA
'1511 '	'13	' MALIGNANT NEO PYLORUS
'1512 '	'13	' MAL NEO PYLORIC ANTRUM
'1513 '	'13	' MAL NEO STOMACH FUNDUS
'1514 '	'13	' MAL NEO STOMACH BODY
'1515 '	'13	' MAL NEO STOM LESSER CURV
'1516 '	'13	' MAL NEO STOM GREAT CURV
'1518 '	'13	' MALIG NEOPL STOMACH NEC
'1519 '	'13	' MALIG NEOPL STOMACH NOS

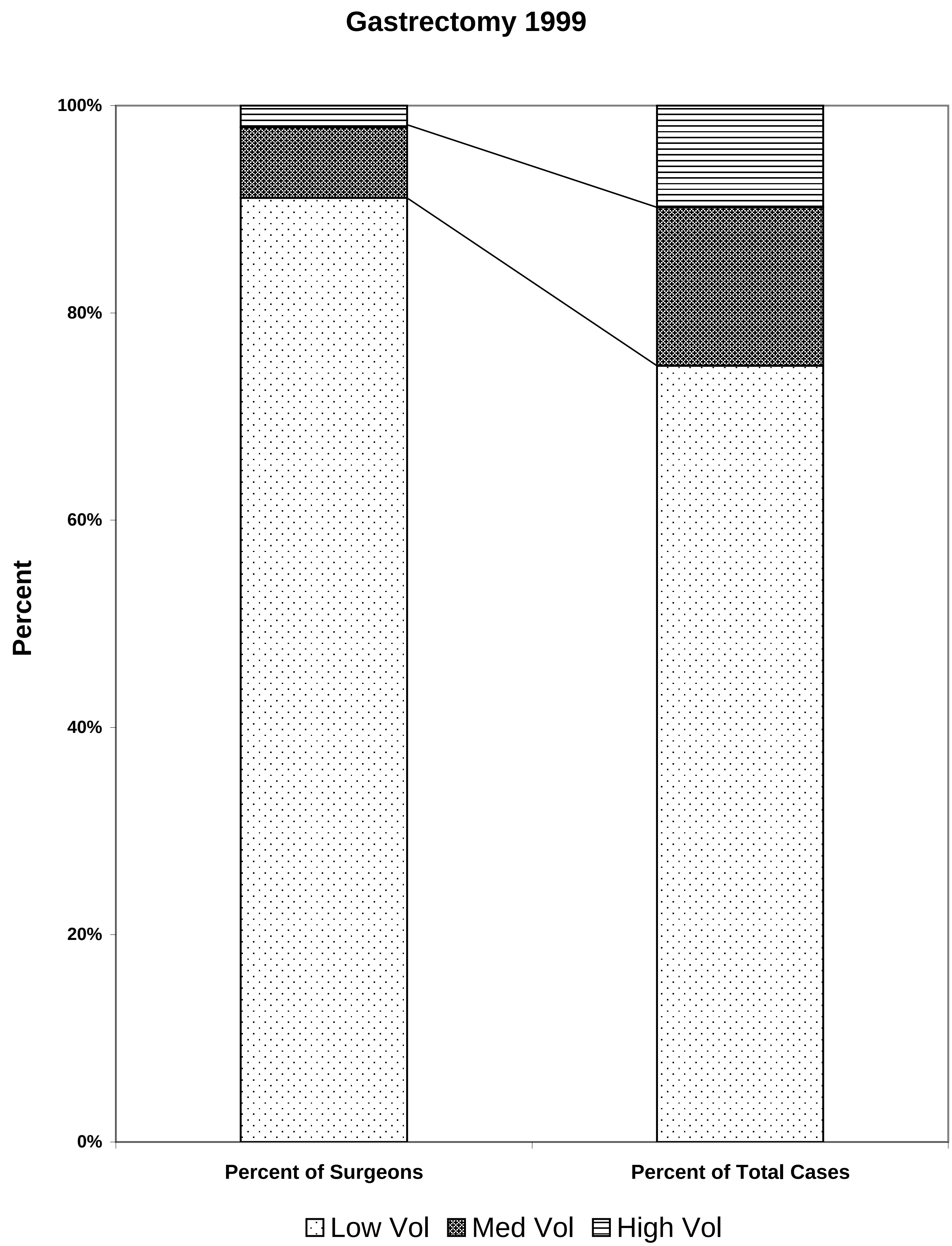
Lung Lobectomy

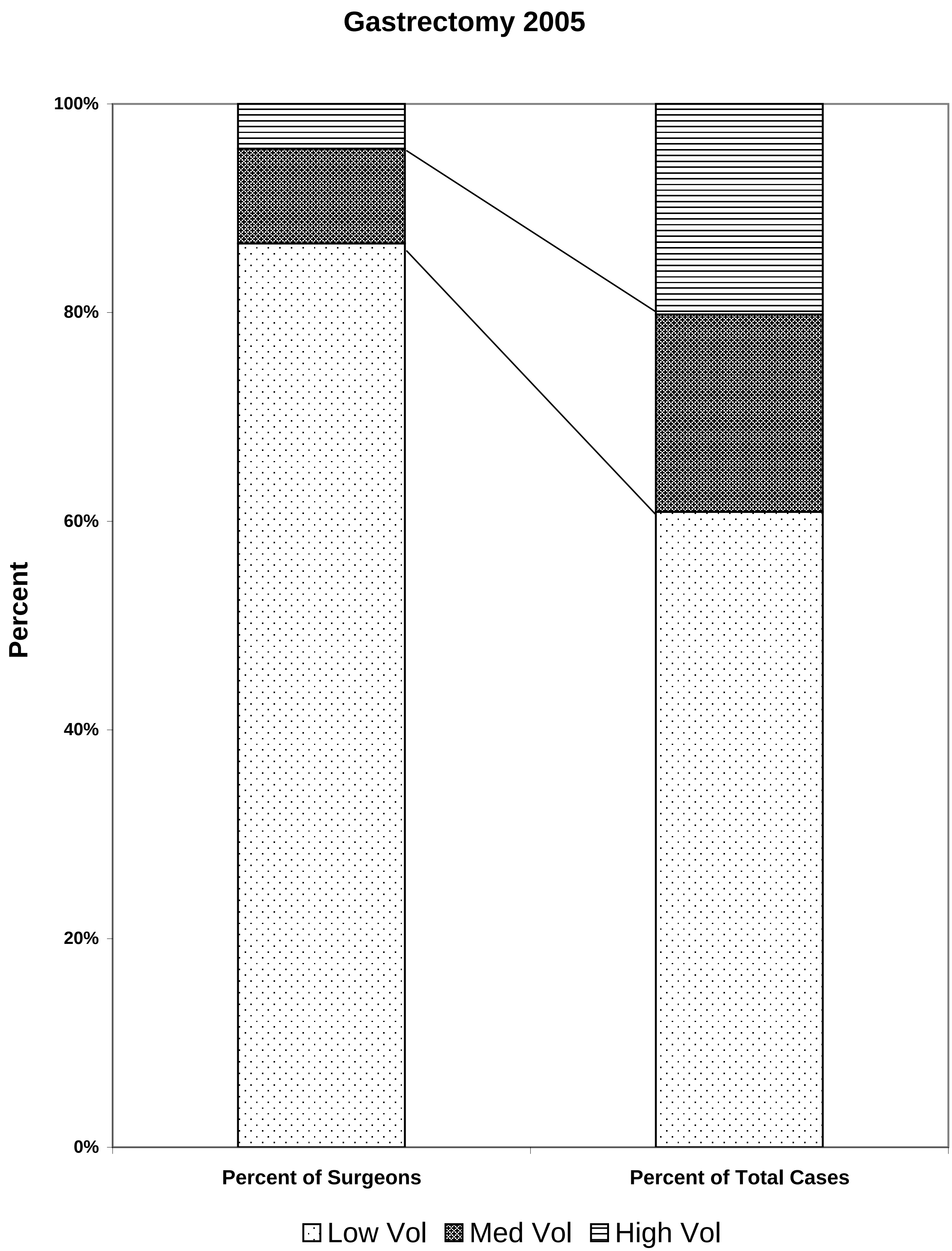
Principal Procedure

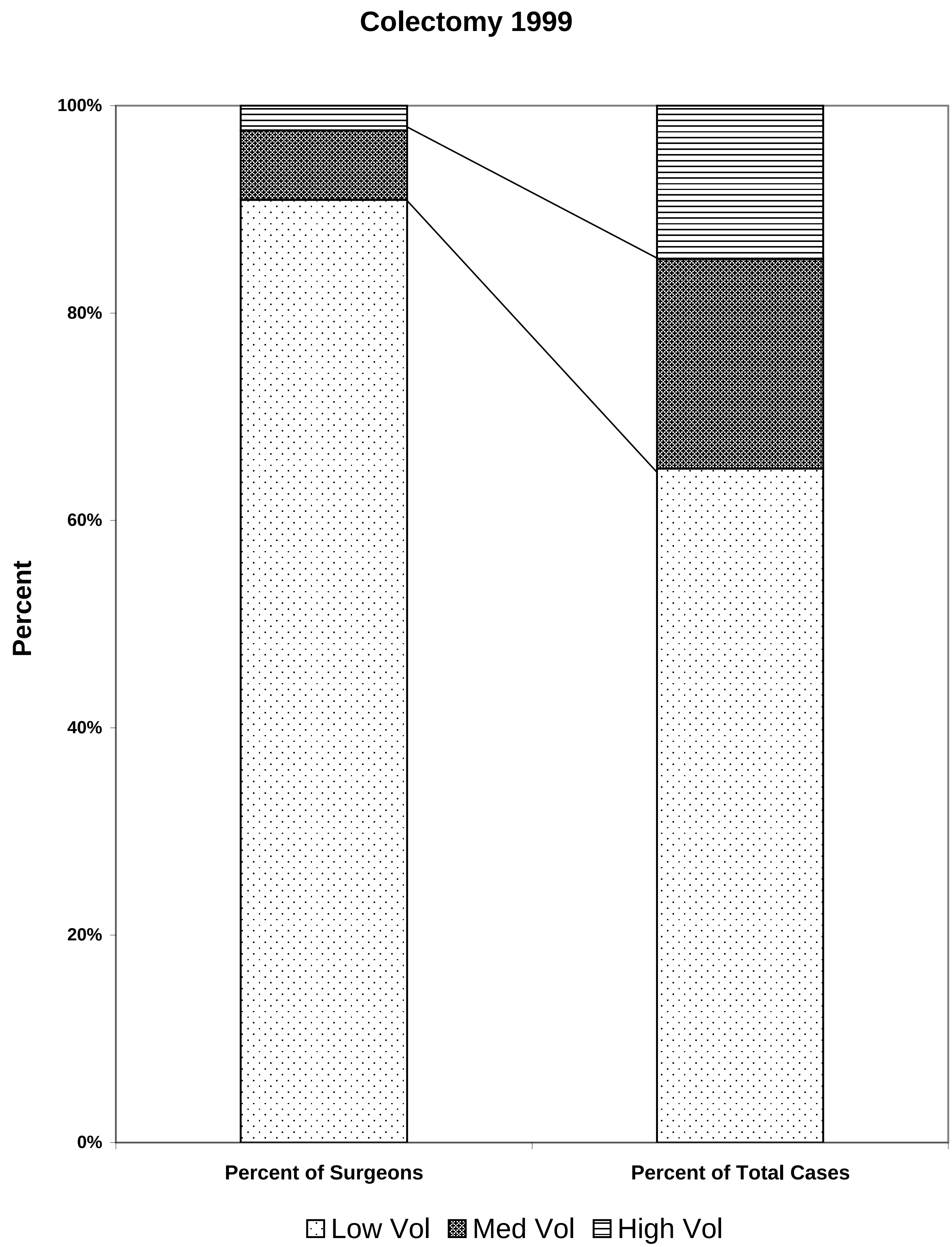
ICD9	CCS	
'3221 '	'36 '	EMPHYSEMA BLEB PLICATION
'3222 '	'36 '	LUNG VOL REDUCT SURG (Begin 1995)
'3223 '	'36 '	OPEN ABLTN LUNG LES/TISS (Begin 2006)
'3224 '	'36 '	PERC ABLTN LUNG LES/TISS (Begin 2006)
'3225 '	'36 '	THOR ABLTN LUNG LES/TISS (Begin 2006)
'3226 '	'36 '	ABLTN LUNG TISS NEC/NOS (Begin 2006)
'3229 '	'36 '	DESTROY LOC LUNG LES NEC
'323 '	'36 '	SEGMENTAL LUNG RESECTION
'324 '	'36 '	LOBECTOMY OF LUNG
'325 '	'36 '	COMPLETE PNEUMONECTOMY

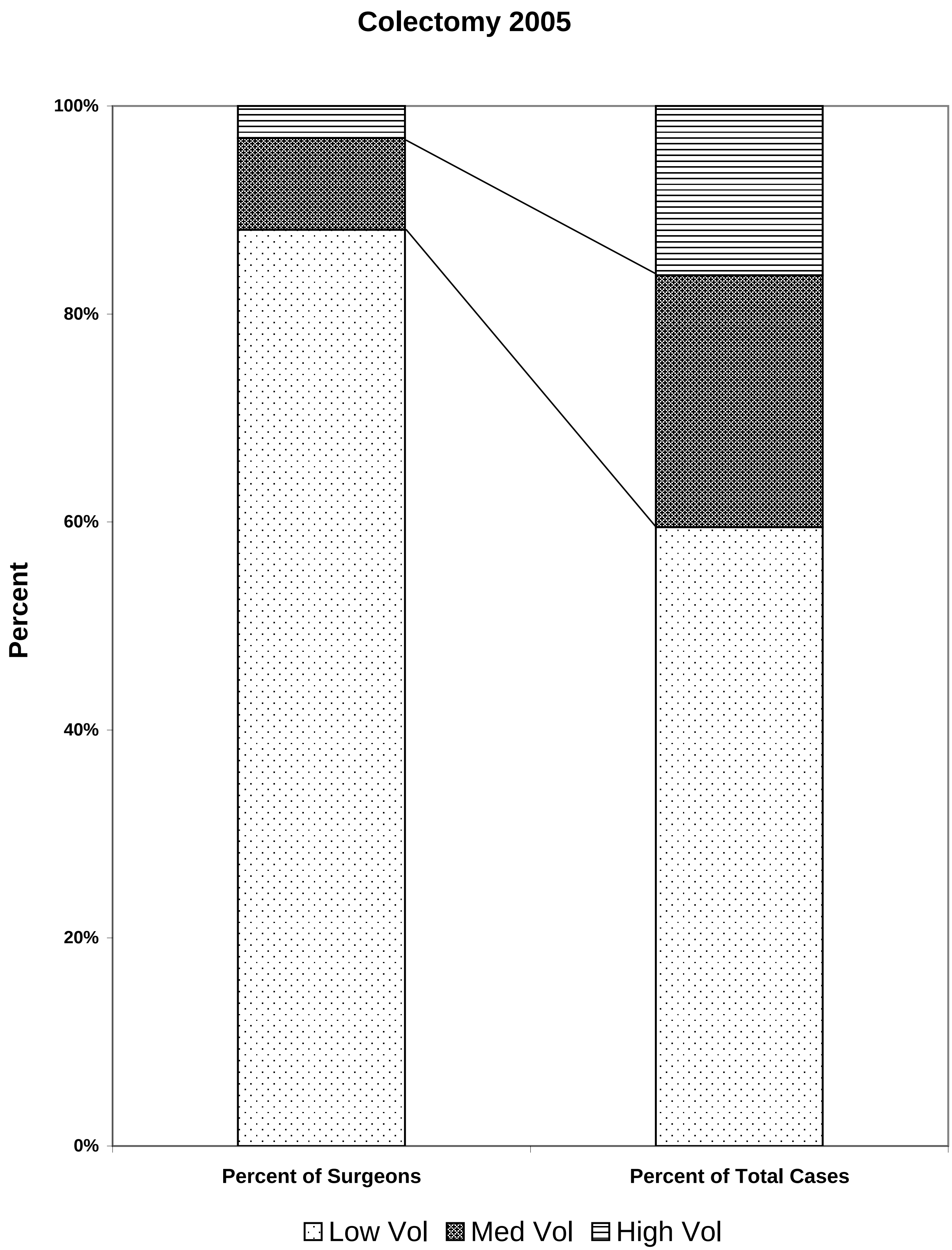
Primary Diagnosis

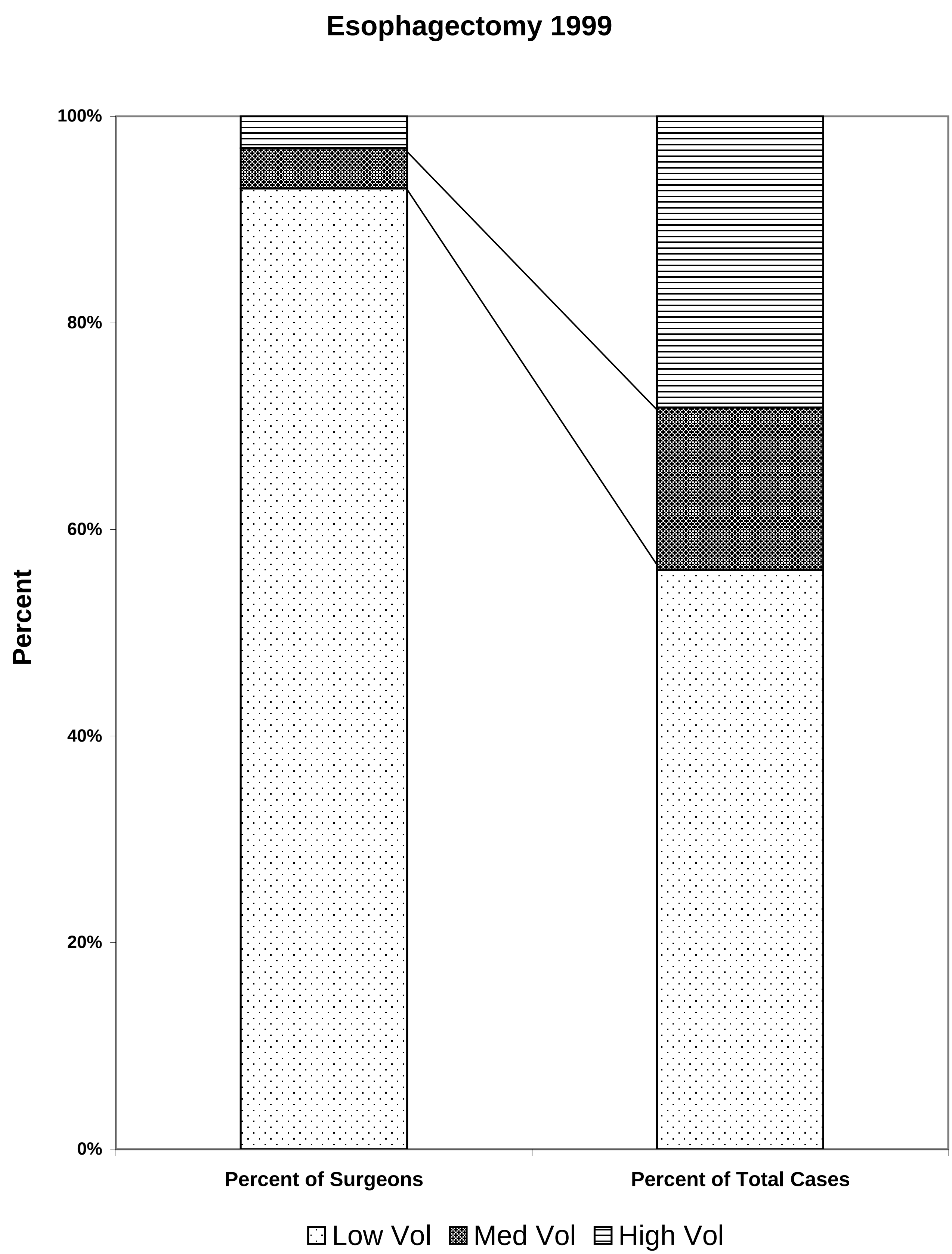
ICD9	CCS	
'1622 '	'19	' MALIG NEO MAIN BRONCHUS
'1623 '	'19	' MAL NEO UPPER LOBE LUNG
'1624 '	'19	' MAL NEO MIDDLE LOBE LUNG
'1625 '	'19	' MAL NEO LOWER LOBE LUNG
'1628 '	'19	' MAL NEO BRONCH/LUNG NEC
'1629 '	'19	' MAL NEO BRONCH/LUNG NOS
'2312 '	'19	' CA IN SITU BRONCHUS/LUNG
'V1011'	'19	' HX-BRONCHOGENIC MALIGNAN

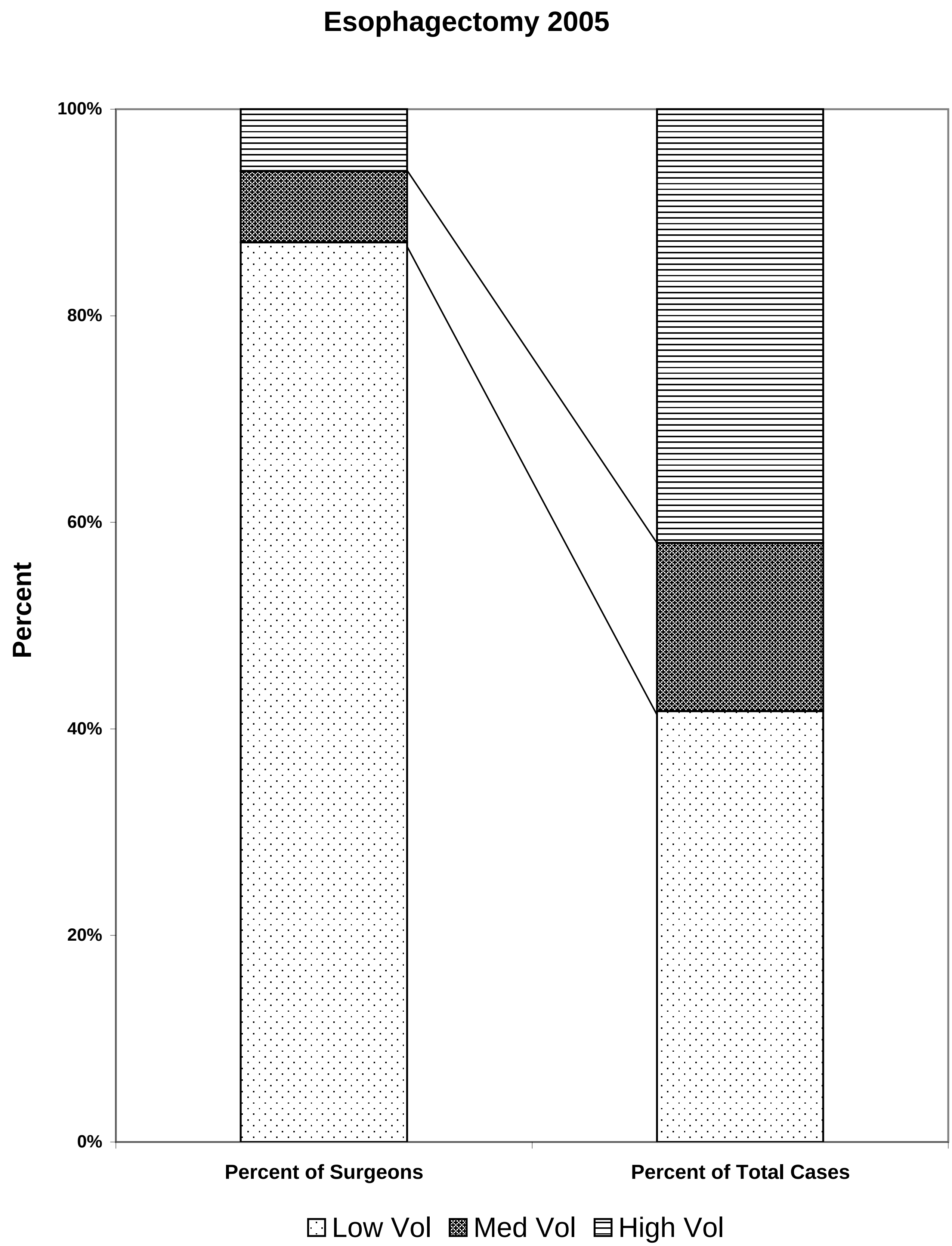

Gastrectomy 1999
Percent
100%
80%
60%
40%
20%
0%
Percent of Surgeons
Percent of Total Cases
Low Vol
Med Vol
High Vol

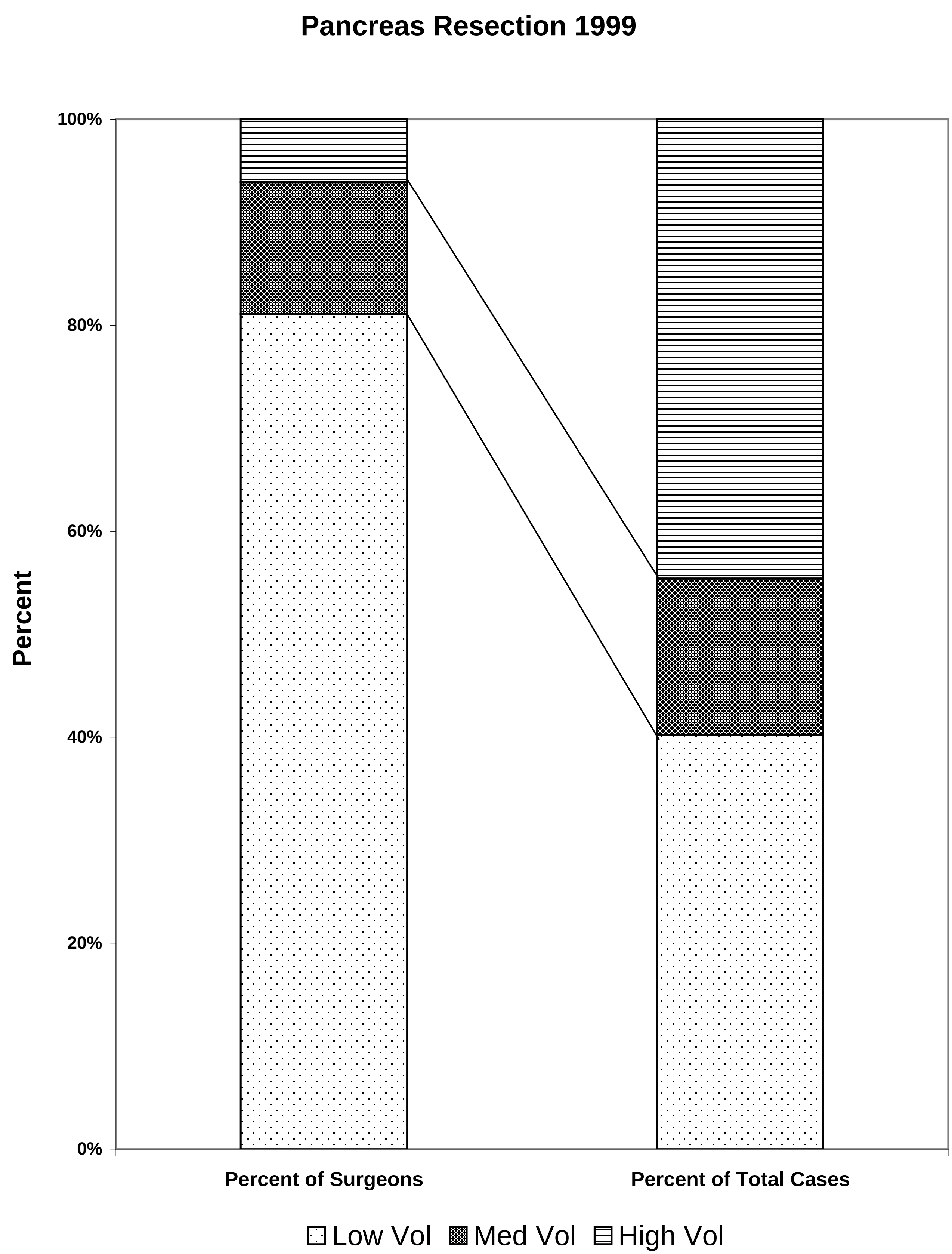

Gastrectomy 2005
100%
80%
60%
40%
20%
0%
Percent
Percent of Surgeons
Percent of Total Cases
Low Vol
Med Vol
High Vol


Colectomy 1999
Percent
100%
80%
60%
40%
20%
0%
Percent of Surgeons
Percent of Total Cases
Low Vol
Med Vol
High Vol

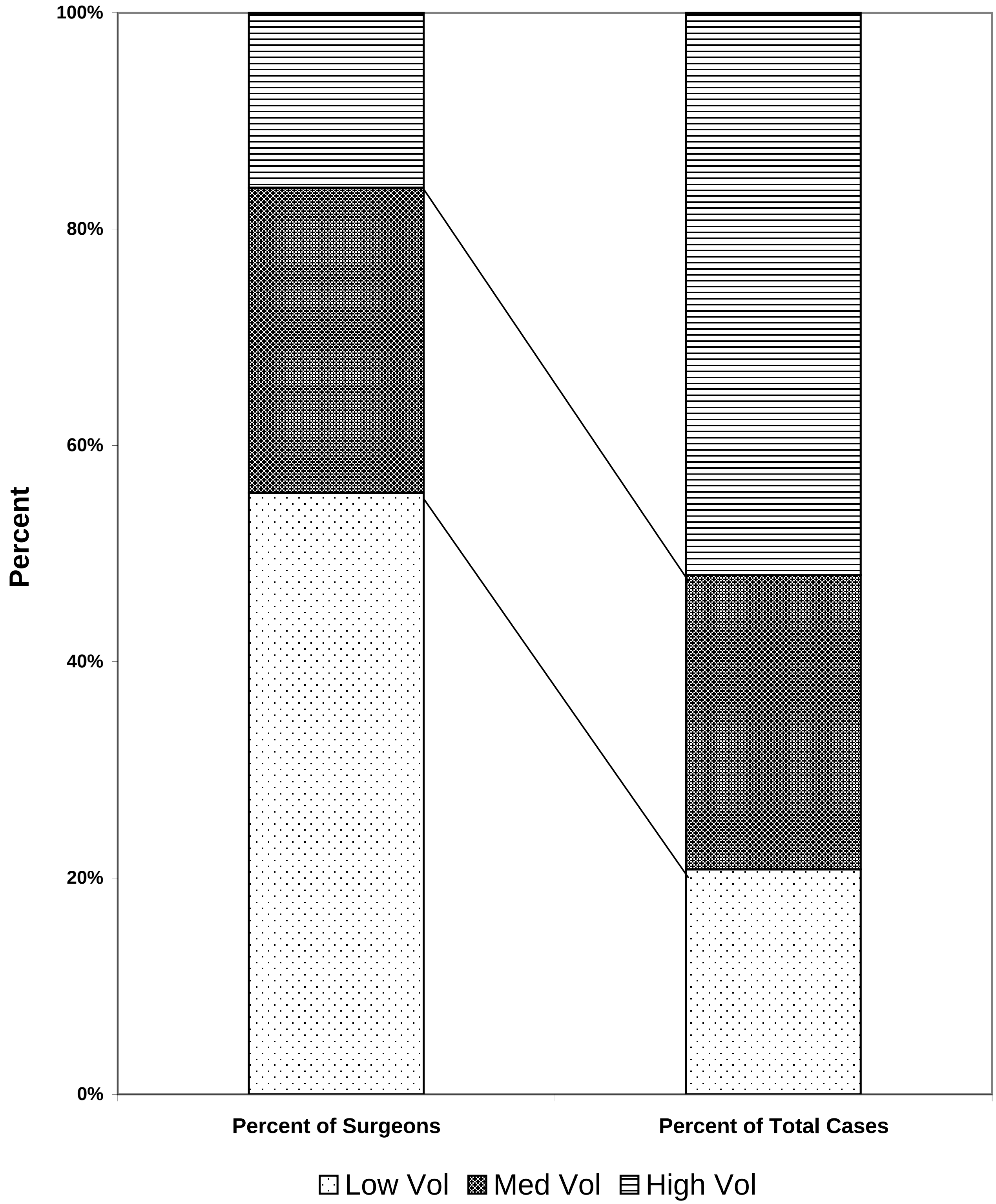

Colectomy 2005
Percent
100%
80%
60%
40%
20%
0%
Percent of Surgeons
Percent of Total Cases
Low Vol
Med Vol
High Vol

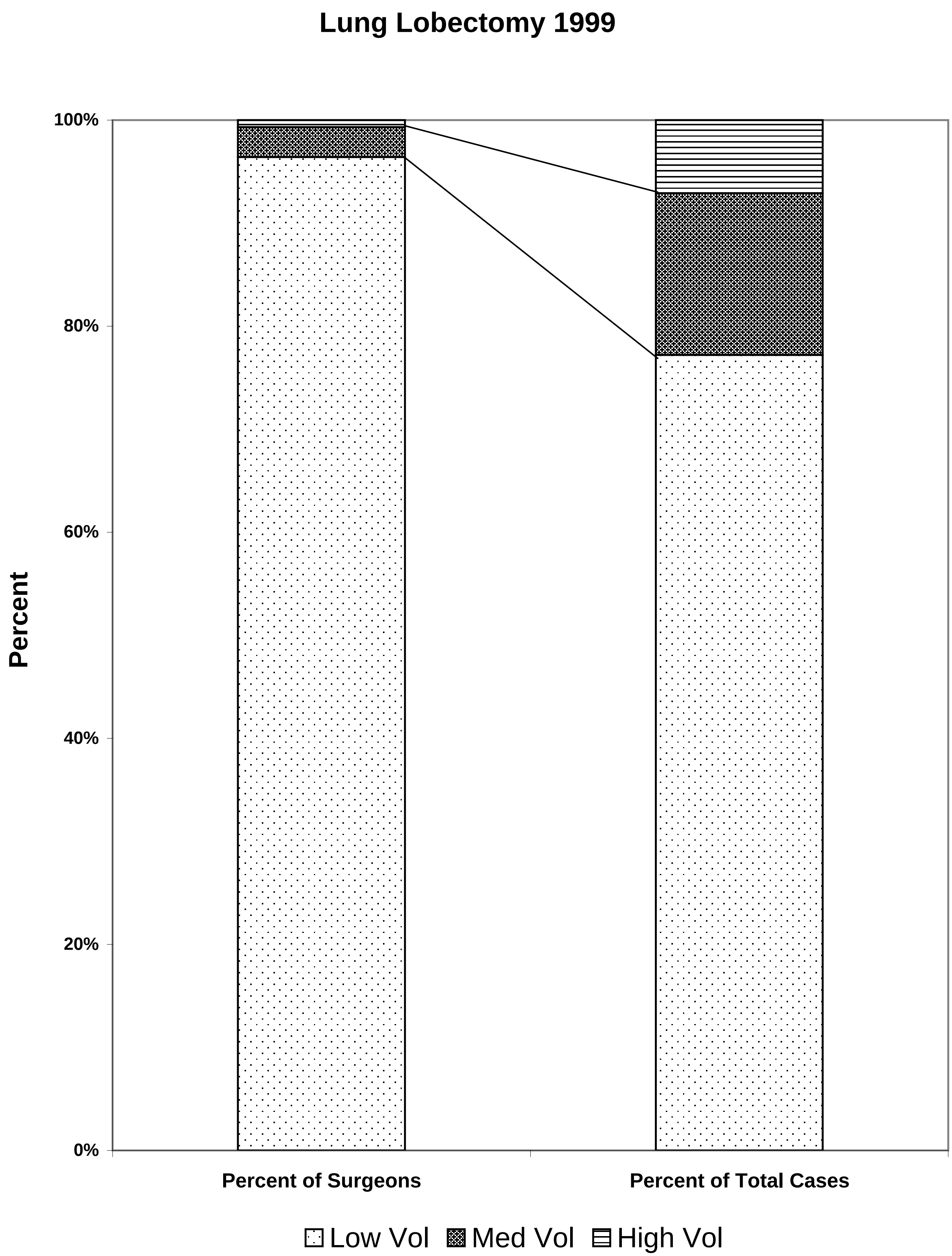

Esophagectomy 1999
100%
80%
60%
40%
20%
0%
Percent
Percent of Surgeons
Percent of Total Cases
Low Vol
Med Vol
High Vol


Esophagectomy 2005
100%
80%
60%
40%
20%
0%
Percent
Percent of Surgeons
Percent of Total Cases
Low Vol
Med Vol
High Vol

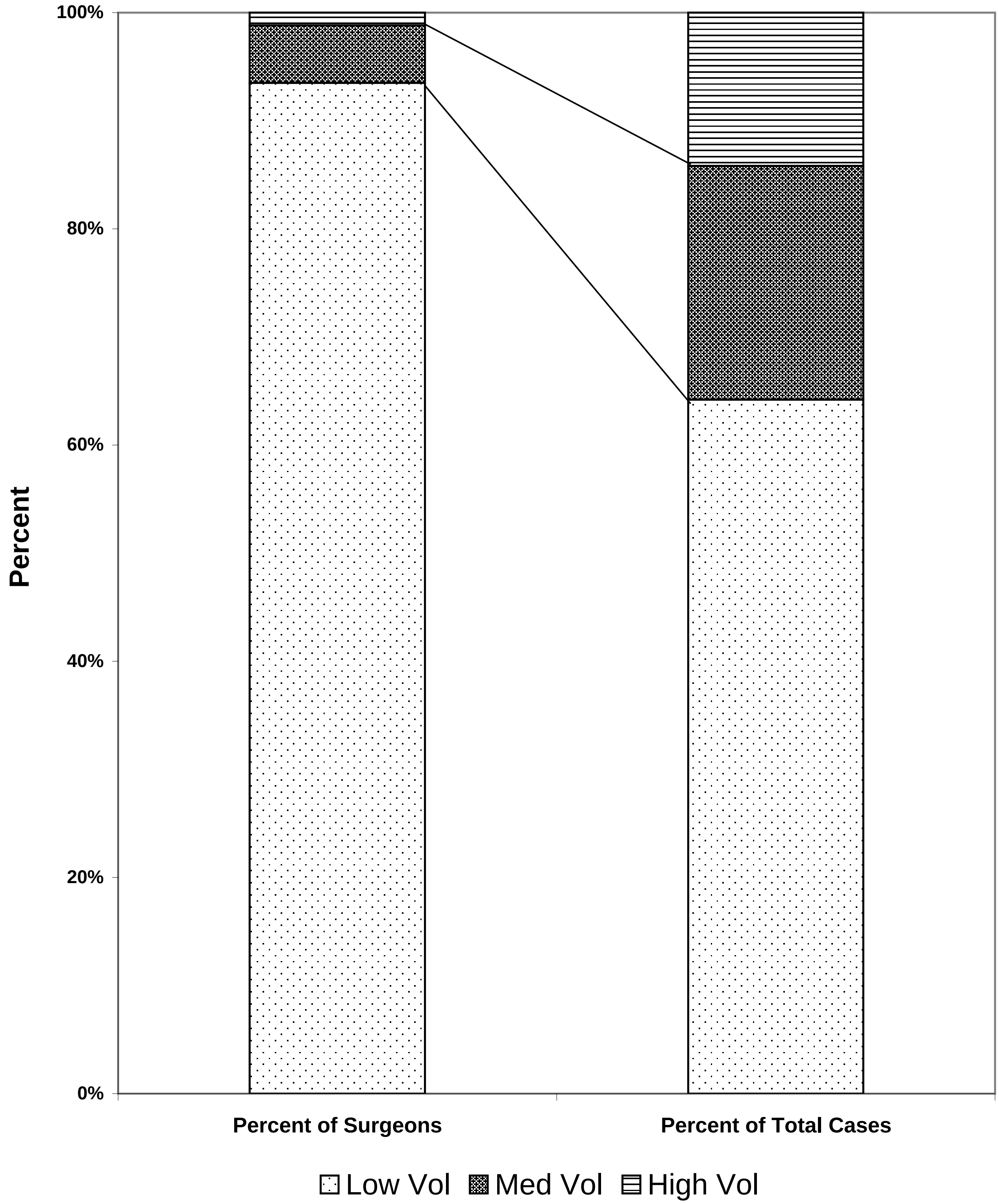

Pancreas Resection 1999
100%
80%
60%
40%
20%
0%
Percent
Percent of Surgeons
Percent of Total Cases
Low Vol
Med Vol
High Vol

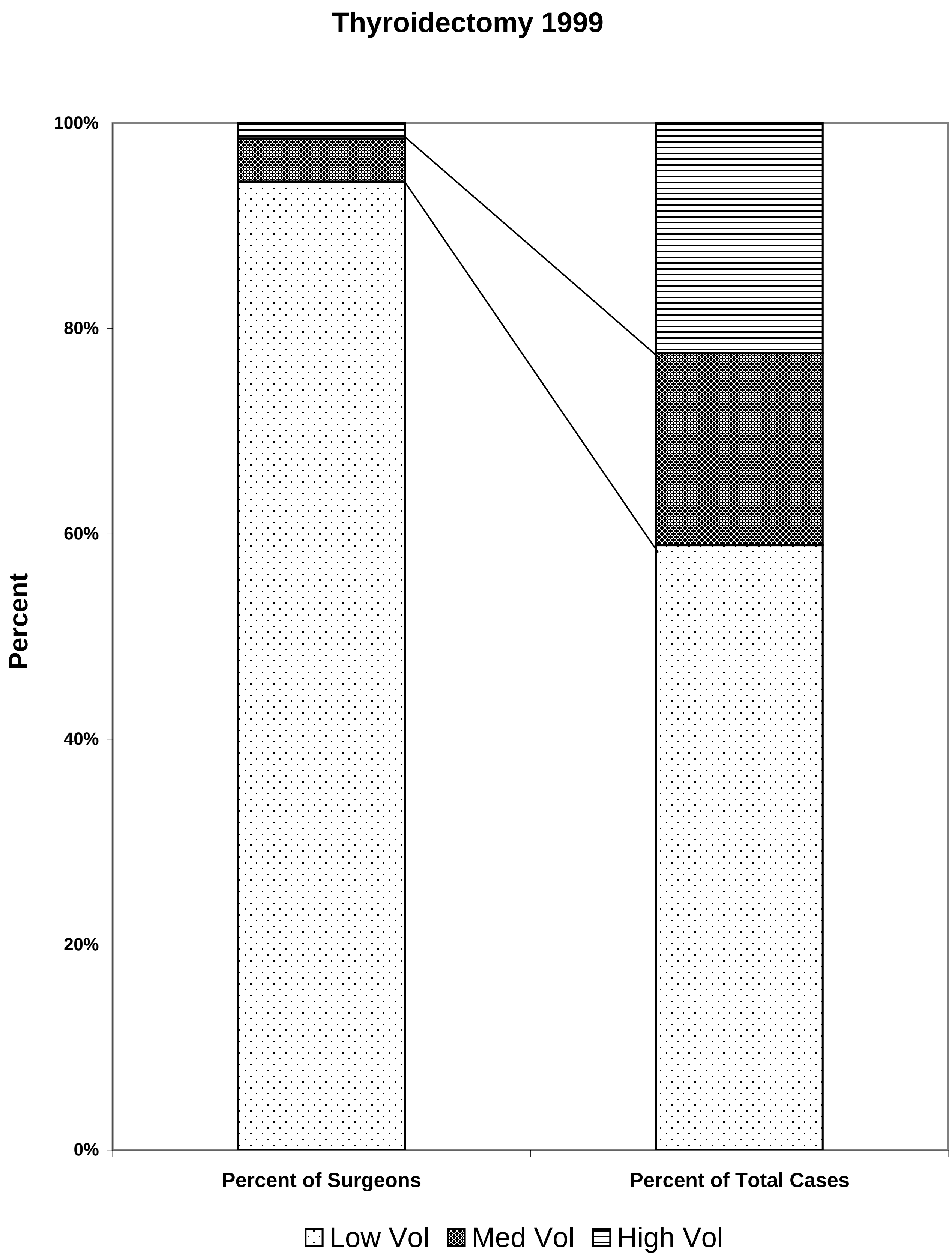
Pancreas Resection 2005



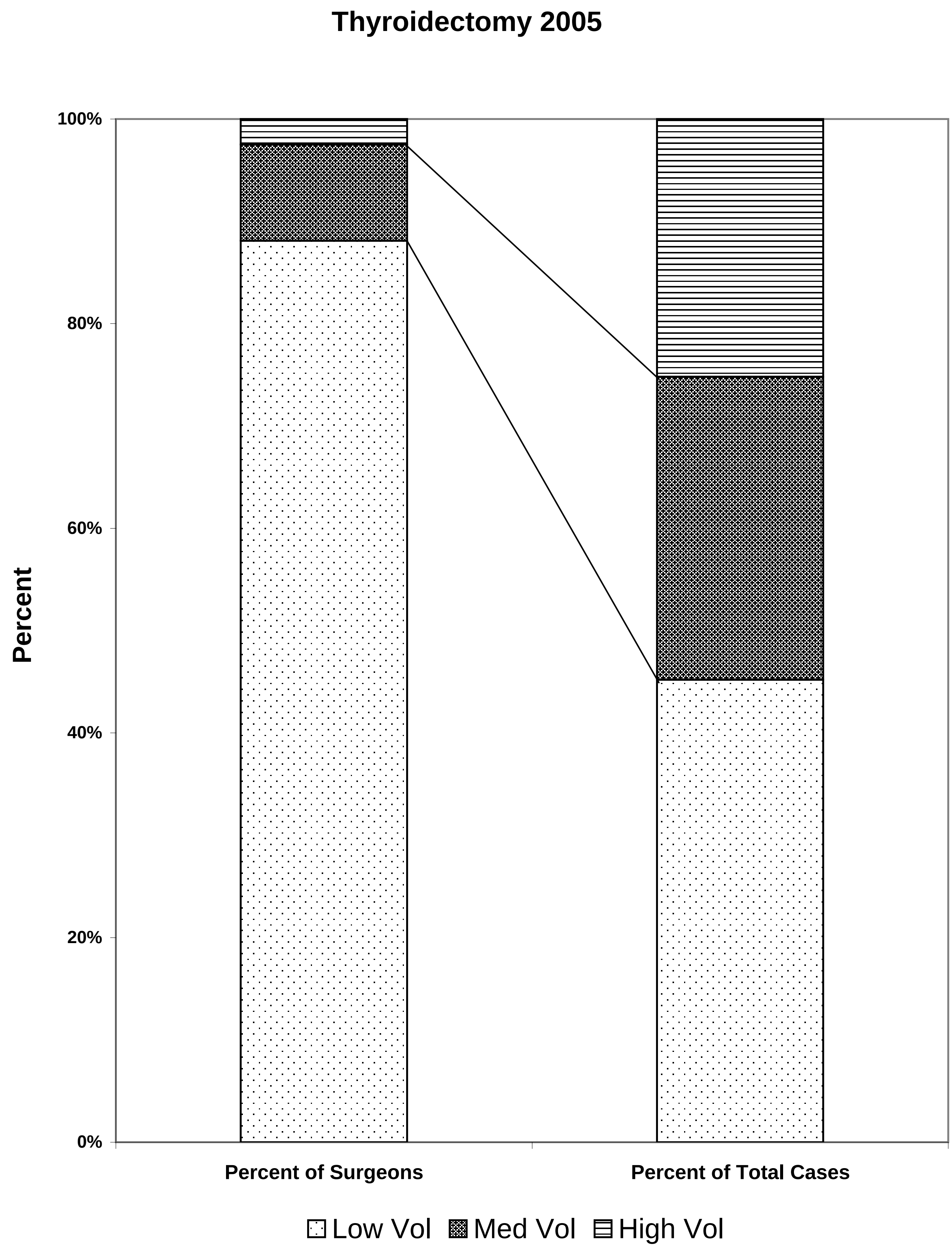

Lung Lobectomy 1999
Percent
100%
80%
60%
40%
20%
0%
Percent of Surgeons
Percent of Total Cases
Low Vol
Med Vol
High Vol

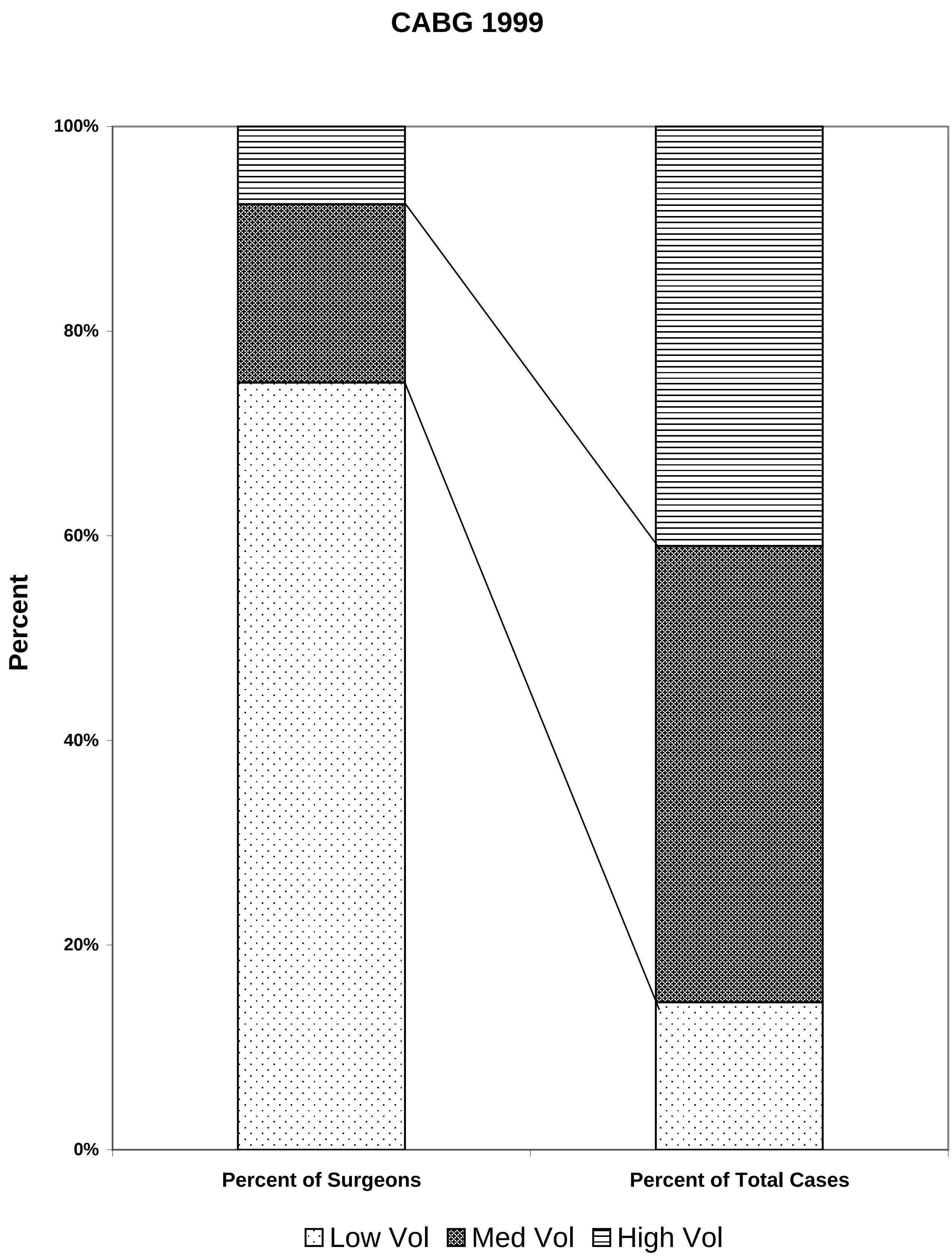
Lung Lobectomy 2005

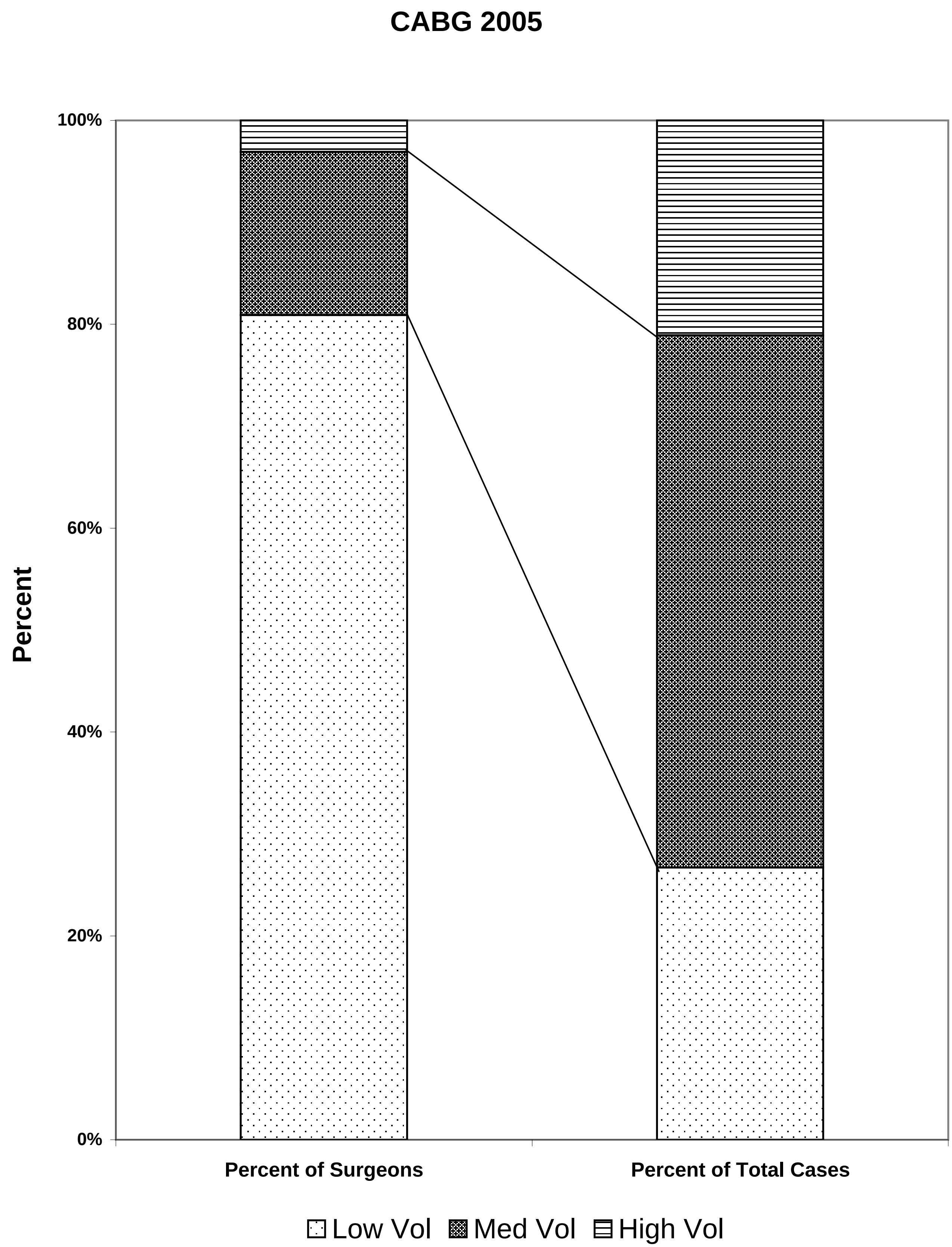


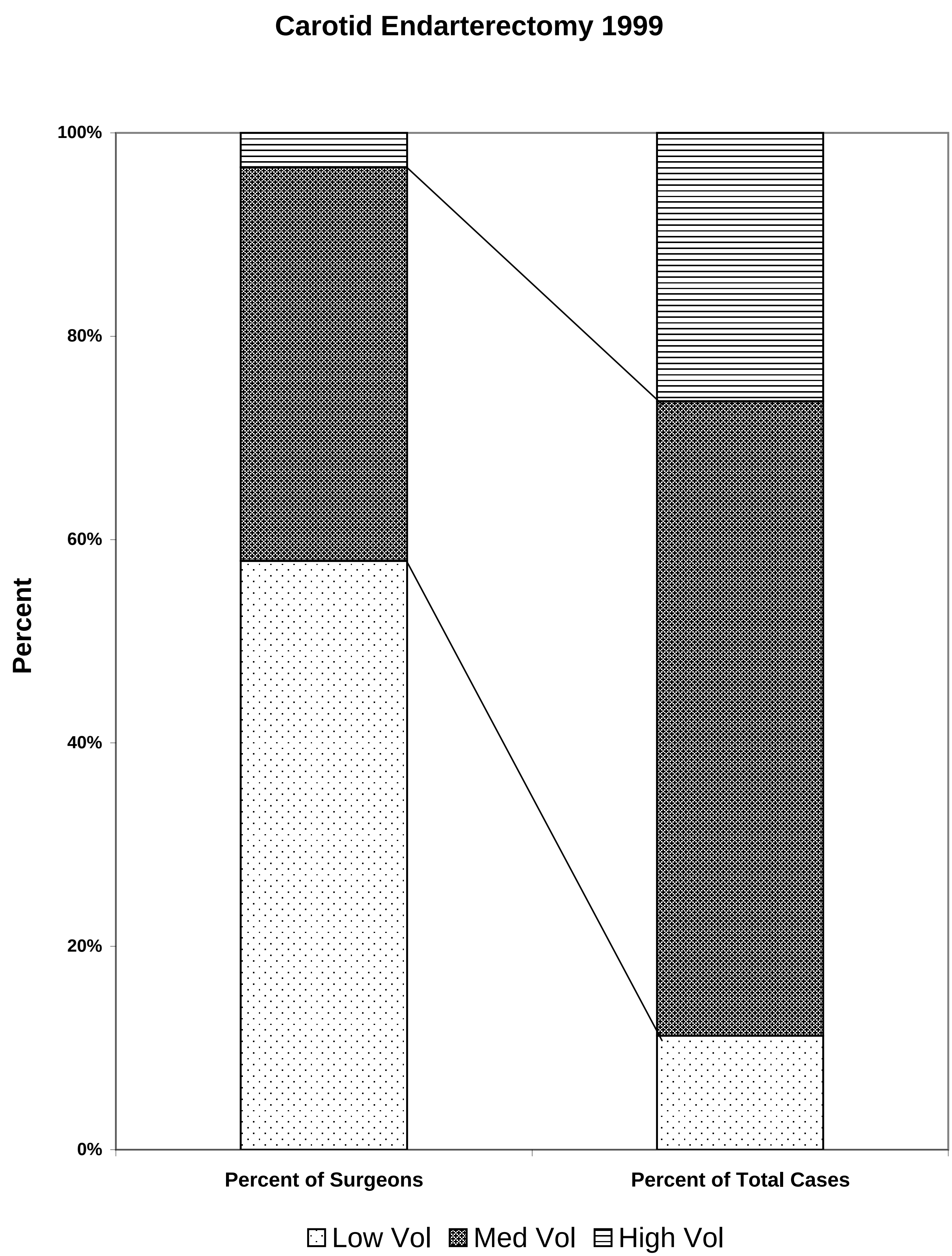


Thyroidectomy 1999
Percent
100%
80%
60%
40%
20%
0%
Percent of Surgeons
Percent of Total Cases
Low Vol
Med Vol
High Vol


Thyroidectomy 2005
Percent
100%
80%
60%
40%
20%
0%
Percent of Surgeons
Percent of Total Cases
Low Vol
Med Vol
High Vol


CABG 1999
100%
80%
60%
40%
20%
0%
Percent
Percent of Surgeons
Percent of Total Cases
Low Vol
Med Vol
High Vol


CABG 2005
Percent
100%
80%
60%
40%
20%
0%
Percent of Surgeons
Percent of Total Cases
Low Vol
Med Vol
High Vol



Carotid Endarterectomy 1999
100%
80%
60%
40%
20%
0%
Percent
Percent of Surgeons
Percent of Total Cases
Low Vol
Med Vol
High Vol

Carotid Endarterectomy 2005